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GRATONITE—A NEW MINERAL FROM CERRO DE PASCO, PERU*

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The mineral here named was sent to the Harvard Mineralogical Laboratory for identification by Mr. Vance of Ward's Natural Science Establishment in October 1938. The same month specimens sent by Dr. Rust of the Geological Staff at Cerro de Pasco were received at Chicago. The name *Gratonite* is in honor of L. C. Graton, Professor of Mining Geology at Harvard University and Consulting Geologist of the Cerro de Pasco Copper Corporation. The occurrence and paragenesis of the new mineral are discussed in the following paper by Dr. Rust.

Crystallography. All the specimens of gratonite seen show the new mineral in crystals only. They vary in size from slender needles 0.1 mm. in diameter and $\frac{1}{2}$ mm. in length to stout prisms 1 cm. across and 1.5 cm. in length. They are generally in radiated groups implanted on a gray siliceous matrix; in some cases they encrust a considerable surface in nonparallel aggregate crystallization. The vast majority of the crystals are very simple, like Fig. 1, with a hexagonal prism and a trigonal pyramid the only forms. Such crystals when short are easily mistaken for slightly distorted rhombic dodecahedrons. Large crystals are clearly subparallel aggregates and their faces are faceted and poor. This is true to a considerable extent of most of the crystals, as the reflections are unexpectedly poor for crystals which look brilliant. Crystals about 1 mm. through give relatively good reflections and were used chiefly for both morphologic and x-ray study. Many of them show narrow and always brilliant truncation of the edges of the principal trigonal pyramid by r and minute brilliant facets of what proved to be a steeper pyramid M (Fig. 2). On one Harvard specimen every crystal showed the flat trigonal pyramid e near the summit of the crystal; this form was observed on a number of Chicago samples (Fig. 3) from both the 300- and 1400-foot levels. The ditrigonal pyramid μ is present as a "line" face truncating the edge a/s (Fig. 3) on a number of tiny crystals in the Chicago collection, and five of the six faces of the upper hexagonal pyramid $(22\bar{4}1)$ were seen as tiny "line" faces truncating the *s*/*m* edge on one Chicago individual on which the *m* faces were relatively large. The pedion *c* was seen on large crystals of one Harvard specimen with large rough faces truncating the whole polar region of the crystal; it gave the impression of a face formed by solution.

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* A preliminary description of this mineral appeared in this journal, **24**, no. 2, 136 (1939).

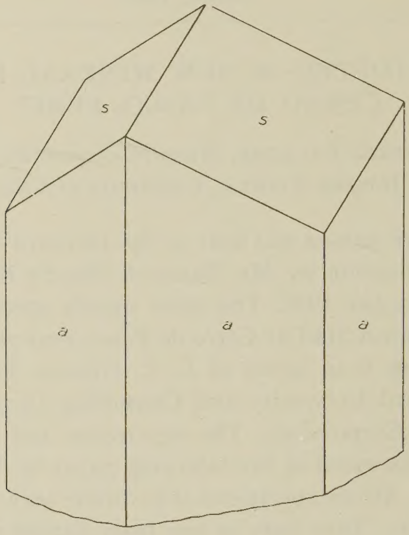


Fig. 1. Gratonite. Commonest type of crystal.

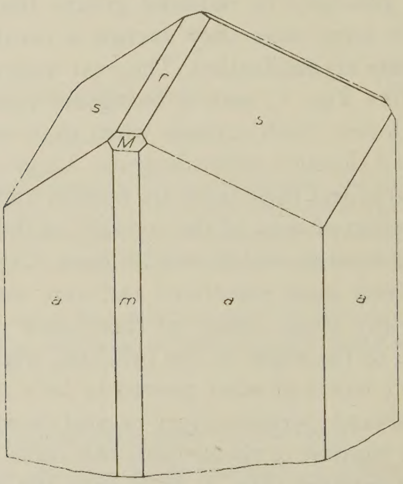
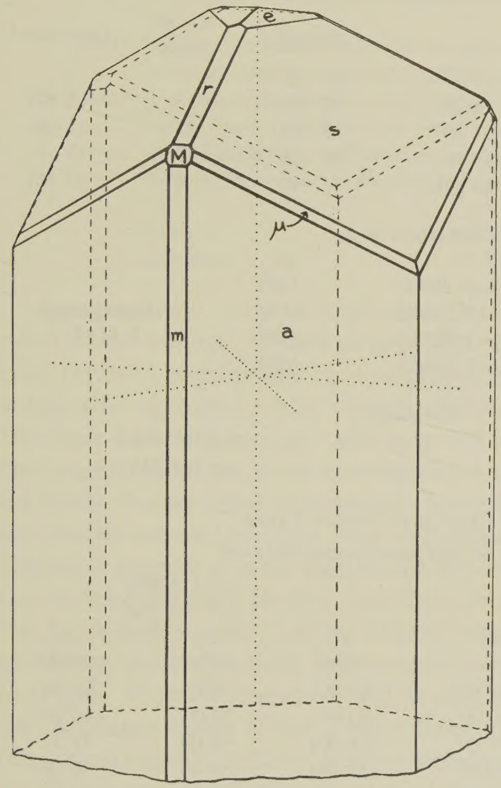


Fig. 2. Gratonite. Crystal showing trigonal prism and pyramids.

The obvious form to choose as the unit is the dominant terminal one. The *x*-ray study, however, gave a unit cell based unequivocally on the truncating form shown in Fig. 2 as *r*. The four trigonal pyramids found (*e*, *r*, *s*, and *M* of Fig. 3) are in the simplest possible relations, two positive and two negative, and each flatter one truncating in turn the edges of a steeper one. Many crystals show unmistakable truncations of three of the hexagonal prism edges in the positive sectants by the trigonal prism *m*, establishing the trigonal character of the vertical axis. But the crystals are almost invariably implanted so as to conceal the lower end;



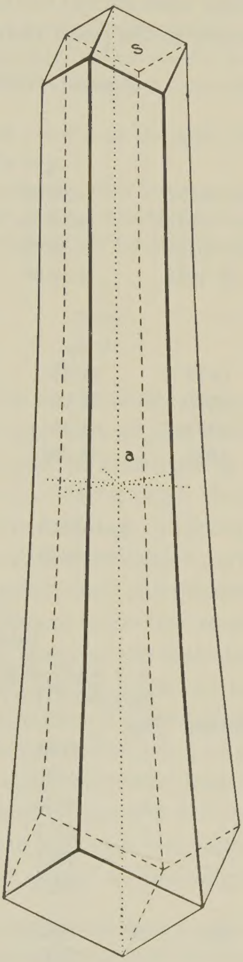


FIG. 3. Gratonite. The most complex combination of forms seen.
FIG. 4. Gratonite. Doubly terminated crystal with swollen basal portion.

in the two doubly terminated crystals found by the senior author the lower end showed the same dominance of *s* as did the positive end. The junior author had ten minute doubly terminated crystals which showed distinct differences in the two groups of terminal forms, and several of these were loaned to the senior author for confirmation; this observation points to the polar character of the vertical axis.

Table 1. Gratonite: Measured Angles on Five Crystals

				Range		No. of faces	Calculated
		ϕ	ρ	ϕ	ρ		ρ
e	$01\bar{1}2$	−30°00′	14°28′	04′	30′	5	14°20½′
r	$10\bar{1}1$	+30 00	27 10	32	49	17	27 04½
s	$02\bar{2}1$	−30 00	45 36	26	48	17	45 38
M	$40\bar{4}1$	+30 00	63 39½	—	40	7	63 56½

Calculation of p_0

	ρ		p_0	
$01\bar{1}2$	14°28′	$\frac{1}{2}p_0=0.25800$	.5160	
$10\bar{1}1$	27 10	$p_0=0.51318$	.5132	weighted mean
$02\bar{2}1$	45 36	$2p_0=1.02117$	.5106	0.5113
$40\bar{4}1$	63 39½	$4p_0=2.01965$	.5039	

Elements

$p_0=.5113$ $\lambda=46°26\frac{1}{2}'$
$c=.4428$ $\alpha=114°04\frac{1}{2}'$

Table 2. Gratonite: Angle Table

Hexagonal—R; ditrigonal pyramidal—3*m*

$a:c=1:0.4428$ $\alpha=114°04\frac{1}{2}'$
$p_0:r_0=0.5113:1$ $\lambda=46°26\frac{1}{2}'$

Bottom	Top		ϕ	ρ	A_1	A_2
	c	0001	—	0°00′	90°00′	90°00′
	m	$10\bar{1}0$	+30°00′	90 00	30 00	90 00
	a	$11\bar{2}0$	0 00	90 00	60 00	60 00
	e	$01\bar{1}2$	−30 00	14 20½	90 00	77 37
$\bar{r}$	*r*	$10\bar{1}1$	30 00	27 04½	66 47	90 00
s	*s*	$02\bar{2}1$	−30 00	45 38	90 00	51 45
$\bar{M}$?	*M*	$40\bar{4}1$	30 00	63 56½	38 55½	90 00
		$22\bar{4}1$	0 00	60 33	64 11½	64 11½
	μ	$24\bar{6}1$	−10 53½	69 43	52 07	72 07

The forms listed in Table 2 may be characterized as follows:

c	(0001)	Seen on one group of crystals as large rough faces, but not characteristic.
m	($10\bar{1}0$)	Confined to narrow faces on alternate edges only of *a* in the positive sectants. Generally not visible.
a	($11\bar{2}0$)	The dominant form on all crystals.
e	($01\bar{1}2$)	Seen not infrequently as a group of tiny faces at the summit of the crystal Not observed on the lower termination.

r	$(10\bar{1}1)$	Present on about half the crystals, generally as narrow but brilliant truncations of the dominant trigonal pyramid. Seen on two crystals by the junior author on a lower termination.
s	$(02\bar{2}1)$	The dominant form on all crystals. Generally brilliant but often unevenly faceted, especially on the larger crystals. Always found on the lower termination as well.
M	$(40\bar{4}1)$	Infrequent, small and very brilliant. In many cases where the faces of a are of unequal size, M forms a line truncation of the edge between a and s. Seen once as but a single face very doubtfully by the junior author on a lower end.
?	$(22\bar{4}1)$	Seen by the junior author as line faces between s and m on the upper end of a single individual on which m is exceptionally large.*
?μ	$(24\bar{6}1)$	A negative ditrigonal pyramid is present occasionally with line faces between s and a. Not seen on lower terminations. That it probably has the symbol assigned is indicated by zonal relationship and by the one approximate measurement obtained, as follows:

	ϕ	ρ
Measured	$-10°00'$	$68°09'$
Calculated	$-10\ 53\frac{1}{2}'$	$69°43'$

Aggregate forms. Reference has already been made to the dodecahedral habit of the stouter crystals of gratonite. In one specimen of this habit each crystal is surrounded by a wreath of slender needles constituting a subparallel aggregate which sheaths all but the end of the crystal; there the plane-faced trigonal pyramid may still be seen in a hollow. Generally the larger crystals are entirely so sheathed and constitute a slightly curving prism: the terminal faces are also faceted or curved. Only the slenderest needles are entirely free from this effect. It appears to be due to an aggregate growth of fairly regular character. While many of the Harvard specimens have their swollen ends free, the smaller needles observed by the junior author were "bustled" at the lower termination. Figure 4 gives an idea of an exceptionally regular specimen of this habit which is $\frac{1}{2}$ mm. in length. It quite resembles one shown in the right center of Rust's Fig. 4. The ρ angles of the lower $\bar{s}$ faces were about 2° too low for the theoretical value (134°22′), which corresponds quite well with the angular change on a prism face ($\rho = 90°$ at the top and $= 88\frac{1}{4}°$ at the base).

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* The crystal in question is .15×.61 mm.; thus the line face $(22\bar{4}1)$ is too small to reflect enough light for a goniometer signal. Its presence was first suspected from zonal relationships when studying the crystal under a binocular at ×56. When mounted on a two-circle goniometer, in which the regular telescope was replaced with a polarizing microscope tube using a 5× ocular and a 20× objective (Leitz UM3 of long working distance), the crystal was oriented by using the Bertrand lens to give a minimized image of the signal from a. This orientation was checked by readings from m, e, and s. When the readings on the circles were then set to pick up the signals from the $(22\bar{4}1)$ faces, these appeared (without the Bertrand lens) as brilliantly illuminated line faces which disappeared (i.e., no longer reflected light into the microscope tube) when either circle was rotated slightly out of the positions computed for $(22\bar{4}1)$.

In short, the mechanism of crystal growth was such that $\bar{s}\wedge a$ appears to remain fairly constant at the expense of $\bar{s}\wedge\bar{s}'$.

The subparallel aggregate crystals are often grouped in spheroids as is very well shown in Rust's photographs. No definite relation between the units constituting these spheroids was apparent to the senior author.

The junior author found one isolated pair of crystals springing symmetrically from a common base. After measuring and plotting these on the stereographic projection he saw that the two individuals were related as a simple type of complex twin involving the simultaneous operation of two mutually perpendicular twinning axes. As shown in the gnomonic projection of Fig. 5, these involve rotations of 60° anti-clockwise around the c-axis and 30° about the a_3-axis (anti-clockwise viewed from the positive end of the a_3-axis marked by the pole of a^{iv}). Measured and calculated angles for two faces of each individual (where a^{iv} has $\phi=0$) follow:

Face	Measured		Calculated	
	ϕ	ρ	ϕ	ρ
a'''	299°30′	90°30′	300°00′	90°00′
s	149°50′	44°52′	150°00′	45°38′
$\bar{a}'''$	234°30′	64°00′	236°20′	64°20′
$\bar{s}$	90°20′	76°00′	90°00′	75°38′

The lower ends of the c-axes of the two individuals start from a common point (Fig. 5); thus the two individuals have a common termination which resembles an orthorhombic pyramid of four faces, a pair from each of the lower trigonal pyramids $\bar{s}$ belonging to each individual. The individuals are like those of Fig. 4 and joined at the swollen ends, which also mark the point of support during growth. Were more examples of this type of intergrowth available, it would certainly be classified as a twin. It cannot be designated a reflection twin over the contact plane (shaded in Fig. 5; indicated by p in the gnomonic projection) since the latter does not have simple indices (they are approximately $73.\overline{73}.0.10$).

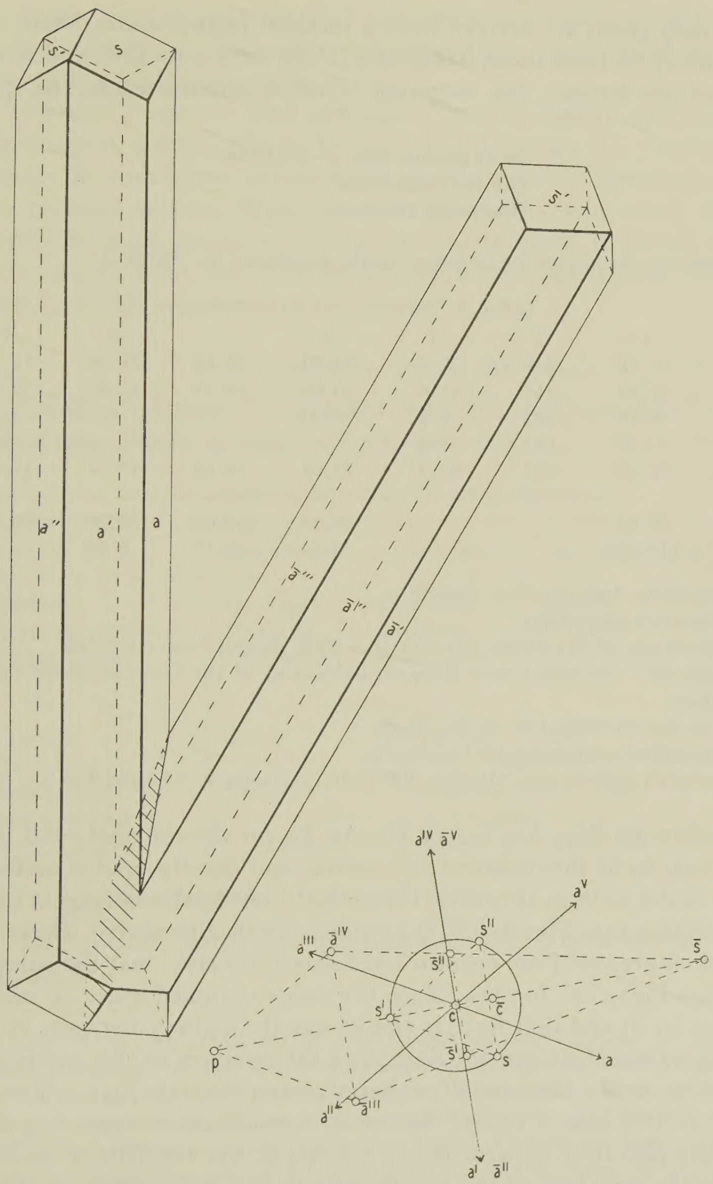

FIG. 5. Gratonite. Intergrown crystal and explanatory gnomonic projection.

X-ray crystallography. Space group C_{3v}^5 ($R\ 3\ m$). $a_0 = 17.69$ Å, $c_0 = 7.83$ Å; $a_0 : c_0 = 1 : 0.4426$; a_{rh} 10.54 Å, $\alpha = 114°05'$. V_0 for hexagonal unit $= 2122$ Å^3, triple that of the rhombohedral unit.

The data given are derived from a rotation picture about [0001] and Weissenberg pictures about [0001] and [11$\bar{2}$0], with zero, first, and second layers of the former. The following omission criteria led to the space group:

$(hk\bar{i}l)$ present when $h-k+l=3n$
$(h.h.\overline{2h}.l)$ with $l=3n$
$(h\bar{h}0l)$ with $2h+l=3n$

Chemistry. Analyses have been made as shown in Table 3.

TABLE 3. ANALYSES OF GRATONITE

	1	2	3	4	5	6	7
Pb	71.12	.343	27.5	70.79	70.49	71.36	71.78
As	10.82	.144	11.6	10.60	11.33	11.47	10.92
Sb	0.21	.002	0.1	0.08			0.21
Fe	0.39	.007	0.6				
S	17.38	.542	43.4	18.01	18.18	17.17	17.09
Total	99.92			99.48	100.00	100.00	100.00
G	6.22±.02			6.1	6.17	6.09	

1. Gratonite. Analysis, F. A. Gonyer.
2. Molecular proportions.
3. Atoms per unit hexagonal cell with $M_0=8000$, derived from x-ray data.
4. Gratonite. Analysis, Oroya Research Laboratory of the Cerro de Pasco Copper Corporation.
5. Calculated composition for $Pb_{27}As_{12}S_{45}$.
6. Calculated composition for $Pb_{27}As_{12}S_{42}$.
7. Gonyer's analysis recalculated to 100% after removing 0.39 Fe and 0.45 S.

The formula $Pb_{27}\,As_{12}\,S_{45}$ (or $Pb_9\,As_4\,S_{15}$ for the rhombohedral unit) seems best to fit the observed cell volume and density, and is preferred by the senior author. However, theoretical considerations suggest to the junior author that $Pb_{27}\,As_{12}\,S_{42}$ is a more probable alternative. These considerations are that from column 3 of Table 3 it is clear that the value for Pb is too high (not too low, since the value obtained must be exactly divisible by 3) and that for S is almost exactly midway between its two possible values of 42 and 45. Now since the numbers of this column are dependent on M_0, they are all probably proportionately high or low, the former in this case. Further theoretical considerations regarding atom sizes may also tend to favor the 42 S formula, but too little is known as regards the structure of the sulpho-salts to generalize safely in this respect.*

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* *Note by junior author:* At the request of the junior author, Mr. A. C. Lundahl (graduate student in the Department of Geology) tested a carefully selected crystal of gratonite in the arc spectrograph (ultra-violet) in the laboratory of Professor W. C. Pierce (Department of Chemistry) and found absence of Bi, Ir, Co, and Ni, Ag less than 0.001%, Cu just over

Tests: Decrepitates violently and melts very easily. Closed tube gives a slight sublimate of arsenic trisulphide (As_2S_3). On charcoal gives a coating of lead oxide and arsenic fumes.

Physical properties. Cleavage none. Fracture slightly uneven to smooth conchoidal. Brittle; $H=2\frac{1}{2}$, $G=6.22\pm.02$ (average of 6 determinations). Color dark lead-gray; streak black. Luster metallic. Opaque; anisotropic in polished section. Weaker anisotropism than any other lead sulpharsenide. Etch reactions: HNO_3—stains iridescent to black; effervesces abundantly after short wait with liberation of free sulphur. HCl, KCN, $FeCl_3$, KOH, negative.

Relation to Other Minerals

Chemical relations. Table 4 lists the significant variations in the minerals most similar in composition to gratonite.

Table 4. Relation to Other Minerals

	Guitermanite	Jordanite	Gratonite	Geocronite
Formula	$Pb_{10}As_6S_{19}$	$Pb_{14}As_7S_{24}$†	$Pb_9As_4S_{15}$	$Pb_5(Sb, As)_2S_8$
Ratio Pb:As+Sb:S	20:12:38	24:12:41	27:12:45	30:12:48
Crystal system	orthorhombic?	monoclinic	rhombohedral	orthorhombic? pseudo-hexagonal
Cleavage	none?	(010) perfect	none	(001)
Hardness	same			
Anisotropism	medium	medium	weak	medium
Etch reactions	same			
Specific gravity	5.9±	6.39	6.22±.02	6.3-6.45

† The junior author prefers $Pb_{14}As_7S_{23}$; see p. 297.

In terms of percentage composition the relations are as shown in Table 5.

0.02%, Fe less than 0.01%, Mg, Mn, and Sn each less than 0.1%, and Sb about 0.1%. In short, it seems certain that the 0.39% Fe found by Gonyer is due to impurity in sampling. If it be assumed that this is present as pyrite (a common associated mineral) and an equivalent amount of S be removed from Gonyer's analysis and the whole recalculated to 100%, the results are as shown in column 7 of Table 3. It is clear that these results are much closer to the 42 S than to the 45 S formula for Pb and for S; as regards As there is (speaking practically) no choice between the two suggested formulae. The density given in column 6 is based on $a_{rh}=10.54$. If the latter figure were 10.48 the density would compute to 6.20. Both of these figures are within probable observational limits of error. While one might expect the observed value of a_{rh} to be low rather than high, nevertheless for a calculated density of 6.20 for the 45 S formula this value must be 10.52. Unfortunately Fe was not determined in the Oroya analysis; so it cannot satisfactorily be treated in a similar fashion.

TABLE 5. COMPARATIVE ANALYSES

	1 Guitermanite	2 Jordanite	3 Gratonite	4 Geocronite
Pb	65.99	68.72	70.96	69.27
As	14.33	12.39	10.71	4.52
Sb			0.15	8.56
S	19.49	18.31	17.70	17.32
Total	99.81	99.42	99.52	99.67

1. Guitermanite. Zuni mine. Hillebrand (*Colorado Sci. Soc., Proc.*, **1**, 129, 1884), recalculated after deducting impurities.
2. Jordanite, Binnenthal. Jackson anal. in Solly (*Min. Mag.*, **12**, 282, 1900). Average of 2 analyses.
3. Gratonite. Average of 2 analyses, by Gonyer and by Cerro de Pasco Co. chemists.
4. Geocronite. Average of 5 closely agreeing analyses, by three chemists.

On the basis of composition alone, the analyses indicate that *gratonite* is certainly different from *guitermanite*, and from *geocronite*, which is essentially an antimony-arsenic sulpho-salt with the Sb:As near 1:1. Considering the probable high quality of the jordanite analyses and the special care exercised in the gratonite analyses, the differences between the two, though small, are significant. The chemical composition is therefore adequate to make a distinction among these minerals.

Physical relations. Gratonite has no distinct cleavage, and only in polished section is there any indication of a weak separation surface parallel to one of the rhombohedral planes. On the other hand, *jordanite* has a very perfect cleavage *b*(010), and *geocronite* is said to have a fair cleavage in one plane. The hardness values of all the minerals discussed here are of the same order (.4 on the Talmadge machine, or "B", i.e. between galena and chalcopyrite). The etch reactions for the lead arsenic sulpho-salts are, in general, the same and are of little diagnostic value. However, *gratonite* shows a weaker anisotropic effect (in an oriented section) than any of the other minerals examined in this study, and this property is therefore of diagnostic value for the determination of *gratonite* in polished section. In the hand specimen, *gratonite* shows little color difference as compared with *geocronite*, but is darker (perhaps by tarnish) than the light steel-gray of *jordanite*. The density of *gratonite* is certainly lower (6.22 ± .02) than that of *jordanite* (6.39) and of *geocronite* (6.3 − 6.45) and probably higher than that of *guitermanite* (5.9 ±).

Crystallographic relations. Gratonite is definitely rhombohedral, as proved by the morphological and *x*-ray studies. *Jordanite* is, with equal certainty, monoclinic, without any simple relation to the crystal elements of *gratonite.* For *guitermanite* we have no crystallographic data, but the x-ray picture of material from the type locality is different from the powder picture of *gratonite*, and it has been elsewhere proposed that *guitermanite* has the same spacings as *jordanite.* The powder picture of *geocronite* (from Sala) is likewise different from that of *gratonite.*

The junior author notes the close homeomorphism between gratonite and tourmaline.

	c	a_0	c_0
Gratonite	.4428	17.69	7.83
Tourmaline*	.4490	15.93	7.15

The habit of certain simple tourmalines on which a and o (equivalent of s on gratonite) predominate, closely resembles that of gratonite. See Figs. 30, 90, 81, 301, 365 and 369 of Goldschmidt's *Atlas der Krystallformen* 9, plates, 1923.

The authors desire to express their indebtedness to Dr. Harry Berman, who determined the density of gratonite and made the x-ray study, as well as the interpretation of the analyses in terms of these data. He also prepared the tables showing the relations of gratonite to other similar minerals.

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* Buerger and Parrish, *Am. Mineral.*, **22,** 1139 (1937).

GEOLOGIC OCCURRENCE OF GRATONITE AT CERRO DE PASCO, PERU*

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General Geology

The copper-silver-gold and lead-zinc mineralizations at Cerro de Pasco are closely associated with igneous activity and clearly hydrothermal in origin. The general geology and major events related to the formation of certain of the ore bodies have been covered in a paper by McLaughlin, Graton and others.[1] Since the appearance of that brief report, numerous bodies of disseminated bornite-chalcocite-tetrahedrite ore have been encountered in a north-south zone within the enormous crescent-shaped pyrite replacement body. This zone may represent the original position of the sediment-agglomerate contact, that is, the wall of the pre-mineralization vent.

A recently discovered ore body of this disseminated type proved to be small in vertical extent. With stoping operations now nearing completion, it is clear that the ore cuts off sharply beneath a flat-lying dike and extends only a few floors below the dike. Apparently the mineralizing solutions, rising along some structural zone of weakness, mushroomed beneath the dike, causing the formation of the small high grade ore body.

It was on the outer fringes of this ore body (1400 level) that gratonite, $Pb_9As_4S_{15}$, was discovered. The more coarsely crystalline specimens were all taken from fractures and solution cavities in a thoroughly leached and altered, siliceous, apparently igneous rock lying on the east side of the stope area. Although it was here that the gratonite was most abundantly deposited, it was found in small amounts in a narrow peripheral zone completely encircling the high grade silver ore. None was found within the central, commercial portion of this ore body, indicating a definite zonal distribution of this mineral and its formation under more mild conditions than the silver mineralization within the stope.

Gratonite has been found in two other localities in the mine. A small amount has been observed replacing galena in a stope 150 feet north of the occurrence described above. Here again it is close to high silver values. In a third occurrence, on the *A* level, 300 feet below the surface, gratonite is associated with high grade copper-lead-zinc ore. The copper values are partly and perhaps entirely secondary, although the presence of chalcopyrite, not heretofore observed in the secondary copper ores of the district, indicates some primary copper mineralization at this spot. An unusual ratio between lead and zinc with this latter occurrence of gratonite suggests that either additional lead was introduced as gratonite after the earlier sphalerite-galena-pyrite mineralization , or that some of the zinc has migrated away as it readily does in the zone of oxidation. The latter interpretation seems correct in view of the presence of secondary chalcocite, since sphalerite is a strong precipitant (by replacement) of copper from descending copper sulphate solutions.

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* Published with the permission of the Cerro de Pasco Copper Corporation.

[1] McLaughlin, D. H., Graton, L. C., and others, Copper in the Cerro de Pasco and Morococha Districts, Department of Junin, Peru: *Copper Resources of the World, XVI International Geological Congress, Washington* 1933, **2,** 513–544 (1935).

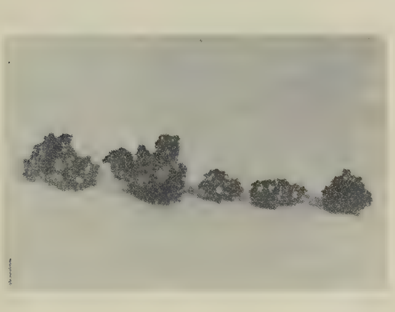

Fig. 1. Nodular clusters of gratonite crystals radiating in all directions from no conspicuous point of attachment. Formed in loose, unconsolidated siliceous material. $\frac{1}{3}$ Natural size.

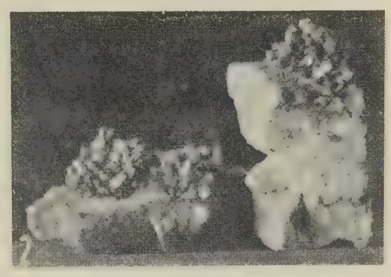

Fig. 2. Hemispherical clusters of gratonite crystals radiating from point of attachment on solid surface formed by solution of host rock. ×.4.

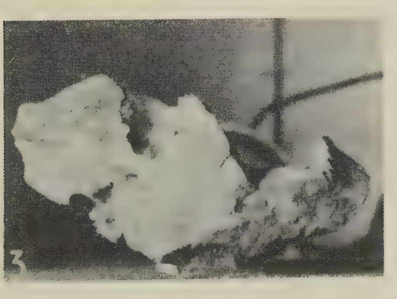

Fig. 3. Small radiating clusters of gratonite crystals formed in solution pockets in siliceous host rock. ×.24.

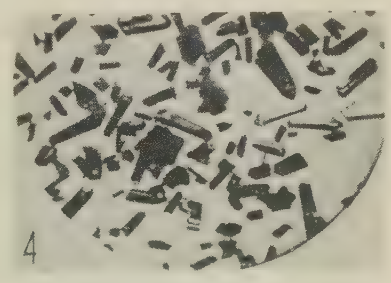

Fig. 4. Small crystals of gratonite brushed from a vug in pyrite. ×8.5.

Occurrence of Gratonite

The ground from which the first specimens of gratonite were taken is unusually open in character, and to this condition is due the perfection of crystal growth, size of individual clusters, and general excellent quality of the material. Preceding the deposition of the lead as the sulpharsenide, the rock is believed to have been subjected to the influence of hydrothermal solutions which vigorously attacked it, removing all but the siliceous material from it. So extreme was this dissolution that a few feet to the north of the loose material in which the gratonite was deposited the ground has collapsed, leaving a large cave. This opening is about forty feet across and averages about fifteen feet in height. Its floor is covered with an unknown thickness of loose material which has caved from the roof. Three sides of this cave are composed of the same porous, siliceous rock, which also carries some gratonite. Locally the siliceous host rock has broken down into a loose sandy mass of quartz grains. Much gratonite occurs in this loose sandy material as isolated clusters of crystals that crudely radiate in all directions as shown in Fig. 1. Where crystallization started on a solid surface, such as in fractures and along solution cavities in the porous host rock, roughly hemispherical radiating masses were formed (see Figs. 2 and 3).

PARAGENESIS

The mineral most closely associated with gratonite is galena. Several types of relationships exist between these two minerals. Not uncommonly gratonite replaces galena along cleavage planes and fractures. Elsewhere galena is deeply corroded and etched along cleavage planes while vugs in the same specimen contain druses of well formed gratonite crystals (Fig. 4). The formation of the silver-copper ore, the dissolution of all but quartz from the rock in which the gratonite was found, and the corrosion of the pre-existing galena, are believed to have been caused by solutions during a single complex epoch of mineralization. Lead derived from the break-down of galena seems to have recrystallized, with little migration, as the then more stable sulpharsenide, gratonite.

Another expression of incipient corrosion of galena along cleavage planes is a very characteristic box-work habit which a fractured surface of galena shows only when it is closely associated with gratonite. Doubtless for every such surface another existed on the opposite side of the fracture, the two matching in a mold-cast relationship, except where tiny cleavage fragments may have fallen out. On a polished surface the edges of the typical triangular pits which galena normally exhibits are frequently seen to be corroded and rough; thus see Fig. 5 in which cleavage planes on a single crystal have been cut approximately at right angles. The box-work areas of galena contain gratonite replacing it in varying degrees from thin blades along cleavage planes to complete substitution. Even where completely replaced by gratonite the material still resembles galena on casual inspection. A few fragments, gouged from one such box-work surface, are shown in Fig. 6. This material, almost wholly gratonite but showing typical cubic outlines, was crushed and the powder is shown in

Fig. 7. Note the rough irregular outlines of the grains showing the absence of cleavage and compare these to the perfect rectangular outlines exhibited by the crushed galena of Fig. 8.

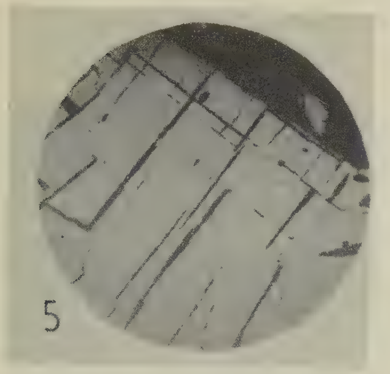

FIG. 5. Dissolution of galena along cleavage planes. This is typical of galena where closely associated with gratonite. ×17.

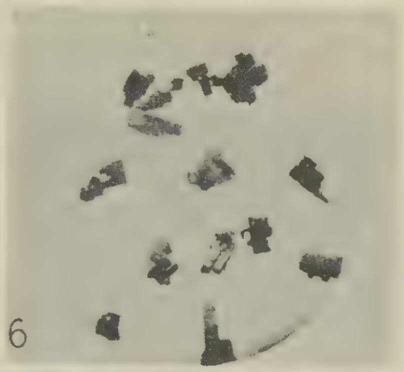

FIG. 6. Fragments of gratonite, pseudomorphic after galena. Gouged from typical box-work surface. ×8.5.

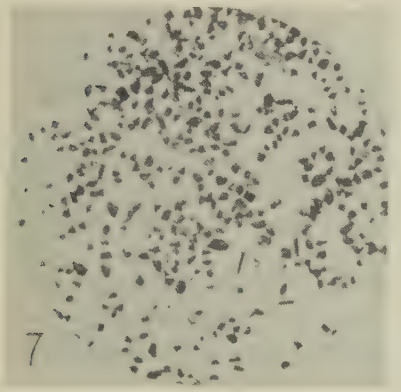

FIG. 7. Grains of gratonite derived from crushing of fragments shown in Fig. 6. Note irregular outlines indicating lack of cleavage. ×9.

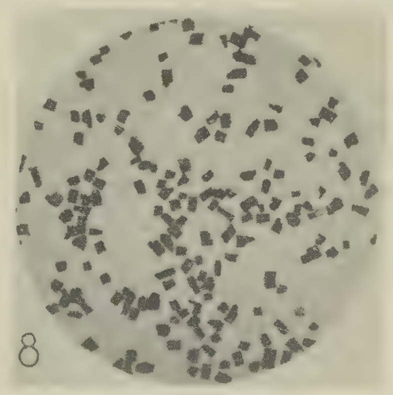

FIG. 8. Grains derived from crushing of normal galena. Compare with grains from gratonite pseudomorphic after galena—Figs. 6 and 7. ×9.5.

In Fig. 9 galena is seen to be veined by gratonite. Figure 10 shows the same area with the galena tarnished by a 20% solution of ferric chloride, leaving the gratonite unaffected.

Copper-Silver Ore Mineral Suite

As mentioned above, gratonite is seen to have veined lead-zinc ore, and to have extensively replaced galena. However, the sphalerite-galena ore belongs to an earlier and distinct stage of the mineralization. A suite of minerals believed to belong to the same ore-depositional stage in which gratonite was deposited includes pyrite, freibergite, chalcocite, bornite and subordinate amounts of bismuthinite, chalcopyrite, covellite, and possibly arsenopyrite. Realgar appears locally but cannot be related definitely to this stage of mineralization. Gratonite was not found in such association with any of these minerals as to permit anything to be said as to the age relations between this mineral and those forming the main ore body. However, the definite zonal distribution of gratonite about the area of heavy silver-copper mineralization indicates its genetic relationship to the solutions responsible for that ore. As mentioned in an earlier paragraph, the lead is believed to have been derived from the dissolution or replacement of galena of an earlier stage and not introduced with the mineralizing solutions that formed the silver-copper ore.

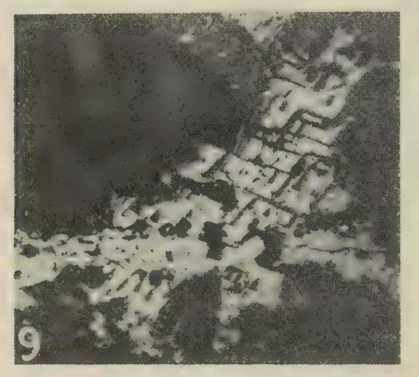

Fig. 9. Galena (gn) veined by gratonite (gr). ×19.

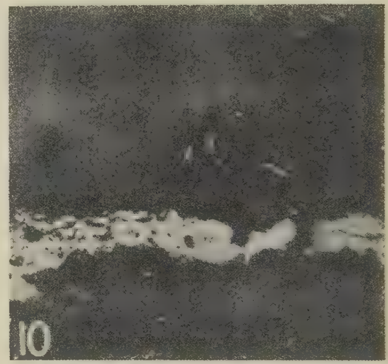

Fig. 10. Same area as shown in Fig. 9. Galena tarnished with a 20% solution of ferric chloride. Gratonite (gr). ×19.

OPTICAL PROPERTIES AND CHEMICAL COMPOSITION OF MAGNESIAN ORTHOPYROXENES*

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Preface

There is urgent need for more accurate chemical and optical data on common rock-forming minerals. Mineralogists have naturally been more interested in seeking and describing the rare, remarkable and beautiful among minerals, and have thus neglected somewhat the everyday minerals with which the petrologist is concerned. A comprehensive investigation to collect such data was begun by the writers in 1934. The present paper is the second article to be published as a result of this plan and a number of others were under way at the time of Professor Phillips' death.[1] These will be completed and published from time to time in the future. In order to call attention to the continuity of the series they will be designated as the "Princeton Investigations of Rock-forming Minerals."

Acknowledgments

The writers are much indebted to Dr. W. F. Foshag of the U. S. National Museum for permitting us to use his new analysis of the enstatite from the Shallowater meteorite, and for giving us some of the powder from which the analysis was made. Material from the Espedalen enstatite was very kindly given us by Dr. H. E. Merwin of the Carnegie Geophysical Laboratory. Professor B. V. Lombaard of the University of Pretoria sent us a piece of the Jagdlust bronzitite, an analysis of which appears in Dr. A. L. Hall's memoir on the Bushveld Complex, and we are also much indebted to Professor Lombard for a new bronzitite analysis and a sample of the rock to accompany it. We wish to thank Dr. E. P. Henderson of the U. S. National Museum for a small amount of the original material of the following previously analyzed pyroxene specimens: Webster bronzite; Johnstown meteorite hypersthene; Nain Labrador hypersthene.

Crystallographic Orientation of Orthopyroxene

In the previous paper by the writers the crystallographic orientation of orthopyroxene as given by Dana and followed by other American texts, was used. This orientation follows the general rule used for orthorhombic crystals, that the *b*-axis be intermediate in length between *a* and *c*. This orientation makes the angle $110\wedge 1\bar{1}0$ equal to approximately 88° and the angle $110\wedge \bar{1}10$ approximately 92°.* In the clinopyroxenes where the orientation is fixed by their symmetry the angle $110\wedge 1\bar{1}0$ is near 92°. It seems, therefore, that it would be much more satisfactory to orient the orthopyroxenes so that they would correspond to the clinopyroxenes, as done in most European texts. This is particularly necessary where intergrowths of the two types of pyroxenes are being considered. The revised orientation considerably simplifies and clarifies the relations. It is. therefore, recommended by the writers that the European orientation be generally adopted in the future, making *b* the shortest axis and the angle $110\wedge 1\bar{1}0$ 92°. With this orientation the optic plane becomes parallel to 100 and the diopsidic lamellae in the orthopyroxenes also lie parallel to this plane. In these respects our previous paper should be revised.

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* Contribution No. 2. Princeton Investigations of Rock-forming Minerals.

[1] Hess, H. H., and Phillips, A. H., Orthopyroxenes of the Bushveld Type: *Am. Mineral.*, **23,** 450–456 (1938).

Scope of This Paper

Though data has been collected for the whole range of compositions exhibited by orthopyroxenes only the magnesian end of the series is fully considered at this time. The range from $En_{100}Of_0$ to En_{70}-Of_{30}[2] is described.[3] Though much data, including a number of new analyses of the more iron-rich orthopyroxenes, are at hand, a number of puzzling relationships have turned up which necessitate further study. Inasmuch as the range En_{100} to En_{70} contains most of the orthopyroxenes commonly found in rocks it was thought advisable to publish this material immediately and hold the remainder until more information could be obtained.

Among the uncertainties encountered in the more iron-rich portion of the series are the following: new optical data and chemical analyses of Bushveld and Stillwater orthopyroxenes, more iron rich than En_{71}, indicating either a discontinuity at about that composition or a marked bend in both the optic angle and index of refraction curves. These orthopyroxenes also have the peculiarity of having two sets of diopsidic lamellae, instead of merely one set, as found between En_{100} and En_{71} in that variety which exhibits the lamellae. One of these sets is the same as that in the magnesian end of the series (parallel to 100), and the other is at a high angle to it, apparently near 112. Still more iron-rich orthopyroxenes from the Adirondacks, near En_{20} in composition, show only one set, the one parallel to 100.

Certain other orthopyroxenes described in the literature suggest no bend or break in the curves at En_{71} so that perhaps there may be two types of iron-rich hypersthenes, one identical in structure with those described in this paper and another different in structure. The analyses now available show no marked chemical differences between the two types.

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* Angle between the poles of these faces.

[2] Of-orthoferrosilite, see Henry, N. F. M.: *Mineral. Mag.*, **24,** 221–226 (1936).

[3] For those analyses quoted from the literature the optical properties in every case were determined or redetermined by the writers on material from the original samples.

It is hoped that these problems will be cleared up during the coming year and the results published.

Chemical Analyses

Larsen[4] has recently discussed the accuracy of chemical analyses of silicates. There has been a general tendency among petrologists to fail to evaluate the degree of error in such analyses. In the present case the materials analyzed are rather simple and do not involve such complicating elements as F and B, so that chemical analysis should be relatively easy. There seems to be a tendency however, for CaO to be low in the analyses, presumably some of the CaO goes into the magnesia precipitate, unless special precautions are taken. It seems likely that the gamma index of orthopyroxenes can be determined with such precision that it gives a more accurate figure for the MgO/FeO ratio in orthopyroxenes than does a first-class chemical analysis. The scattering of the points on either side of the gamma index curve is probably largely the result of slight errors in the chemical analyses, and to a lesser extent it is due to errors in the optical work or the effects of minor constituents.

It is very difficult to obtain a perfect separation of a rock-mineral from the other constituents of the rock. On the specimens prepared in this laboratory the chief method of removing impurities was by repeated separations in a Franz isodynamic magnetic separator. Hand picking and heavy liquid separations were used as well in some cases. If only a small percentage of impurities are present in the sample analyzed, and *their amount* and *composition* known with a fair degree of accuracy, no great disadvantage is encountered as the analysis may be recalculated minus these constituents. In this case, however, there will be some uncertainty concerning minor constituents present in the bulk analysis in very small amounts.

The three analyses given in Table 1 below are considered thoroughly reliable in every respect. They have been made by experienced analysts of well-known reputation. The materials analyzed have been examined by the authors. They are practically free of all impurities.

These three analyses are about evenly spaced along the range of compositions investigated. They have been used as key specimens for the determination of the gamma index curve and have been given more weight in determining the position of the curve than the other analyses. No doubt some of the remaining nine analyses given in Table 2 are of equal quality. In others the amount and nature of the impurities is not known with sufficient accuracy and slight errors in analysis are suspected. Nevertheless all of the analyses may be considered reasonably reliable and of high quality as mineral analyses go. Data are given in the notes on each analysis concerning the impurities present, their amount and the accuracy with which this is known, and remarks are made regarding any known or suspected deficiencies of the analyses themselves.

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[4] Larsen, Esper S., *Am. Jour. Sci.*, **35,** 94–103 (1938).

In several cases a slight alteration of the orthopyroxene to a colorless or pale green amphibole has been noted. Fortunately this alteration does not change the bulk composition very much and may, as a rule, be neglected. The MgO:FeO:CaO ratios do not seem to be appreciably disturbed, though there may be a slight reduction in the amount of SiO_2 present and an increase in H_2O. Inasmuch as the curves are based on the MgO:FeO ratio they are not affected.

In a general way, but with no great regularity, TiO_2 and MnO increase with increase in FeO. CaO increases with increase in FeO from enstatite to En_{50}, or thereabouts, and then probably decreases again (Fig. 4).[a] Al_2O_3 shows a tendency to increase with increase in FeO from enstatite to $En_{50}Of_{50}$, but varies rather irregularly. Fe_2O_3 is very low in pure enstatites but shows no marked variation through the range of hypersthenes to orthoferrosilite.

TABLE 1

	1	2	11
SiO_2	59.92	57.28	51.81
Al_2O_3	.00	0.90	2.16
Fe_2O_3	.00	0.42	4.52
FeO	0.38	6.43	13.96
MgO	39.51	34.94	24.57
CaO	0.32	0.13	1.95
Na_2O	.00	0.22	0.39
K_2O	—	0.01	0.03
H_2O+	—	0.13	0.19
H_2O-	—	—	—
TiO_2	—	0.05	0.76
P_2O_5	—	—	—
Cr_2O_3	—	—	—
MnO	—	tr	0.16
	100.13	100.51	100.50

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[a] Excluding those orthopyroxenes which occur in rocks deficient in CaO, and some that have crystallized at lower temperatures than normal.

$\frac{\text{En}}{\text{En}+\text{Fs}}\times 100$	99.5	90.8	76.0
$\frac{\text{Di}}{\text{Di}+\text{Hy}}\times 100$	1.1	0.4	8.3
γ	1.6592	1.6750	1.6967
β	1.6525	—	—
α	1.6508	—	—
$\gamma-\alpha$	.0084	—	—
2V	54½°	—	(79⅜°)
Optic Sign	+	+	−
Lamellae	−	−	+
SiO_2	59.84	56.98	51.55
Al_2O_3	.00	0.90	2.15
Fe_2O_3	.00	0.42	4.50
FeO	0.38	6.40	13.89
MgO	39.46	34.76	24.45
CaO	0.32	0.13	1.94
Na_2O	.00	0.22	0.39
K_2O	—	0.01	0.03
H_2O	—	0.13	0.19
TiO_2	—	0.05	0.75
P_2O_5	—	—	—
Cr_2O_3	—	—	—
MnO	—	tr	0.16
	100.00	100.00	100.00

1. Enstatite, Shallowater meteorite. Analyst W. F. Foshag. No impurities.

2. Enstatite, Espedalen Norway. Analyst Washington. No impurities. (Optic angle could not be determined because material was ground to a fine powder and grains were too small to measure on the universal stage. Index determination with a high power objective presented no difficulty). Reference: Washington & Merwin, *Am. Mineral.*, **8,** 63–64 (1923).

11. Hypersthene, Nain, Labrador. Analyst Washington, No impurities. Optic angle abnormal. Reference: same as preceding analysis.

TABLE 2

	3	4	5	6	7	8	9	10	12
SiO_2	53.61	55.76	55.60	55.40	54.68	53.60	53.65	52.16	53.20
Al_2O_3	1.67	1.66	2.96	1.60	1.80	3.51	1.03	3.91	2.24
Fe_2O_3	1.48	1.34	1.19	.00	0.50	0.79	1.59	—	0.83
FeO	6.70	7.17	6.97	9.35	9.19	11.38	13.82	13.39	15.15
MgO	33.15	32.42	29.45	32.45	30.19	25.34	27.69	27.60	24.58
CaO	2.32	0.74	2.37	0.45	2.22	4.19	1.06	1.97	2.61
Na_2O	0.04	0.03	0.69	tr	0.04	0.25	0.03	—	0.06
K_2O	0.06	0.04	0.21	tr	0.03	0.03	0.00	—	0.01
H_2O+	0.54	0.43	0.26	0.00	0.46	0.27	0.51	—	0.48
H_2O-	0.08	0.08	0.02	0.15	0.05	0.04	0.01	—	0.10
TiO_2	0.09	tr	—	0.10	0.11	0.29	0.18	—	0.26
P_2O_5	tr	0.10	0.02	0.20	0.02	—	—	—	tr
Cr_2O_3	0.38	0.33	0.62	0.65	0.47	—	0.30	0.69	0.10
MnO	0.16	0.21	0.20	0.15	0.21	0.19	—	0.56	0.32
	100.28	100.31	100.56	100.60*	99.97	99.88	99.87	100.28	99.94
$\frac{100\ En}{En+Fs}$	89.7	88.7	88.4	86.3	85.6	79.4	78.6	76.9	74.5
$\frac{100\ Di}{Di+Hy}$	8.5	2.8	7.6	5.6	8.4	8.7	4.2	7.8	10.6
γ	1.6770	1.6790	1.6798	1.6816	1.6826	1.6920	1.6930	1.6959	1.6985
β	—	1.6733	—	—	—	—	—	1.6921	—
α	—	1.6679	—	—	—	—	—	1.6837	—
$\gamma-\alpha$	—	0.0111	—	—	—	—	—	0.0122	—
2V	87¼°	89½°	88¼°	86°	83½°	73¼°	70½°	69¼°	65¾°
Optic Sign	+	−	−	−	−	−	−	−	−
Lamellae	+	weak	+	+	+	+	+	−	+
SiO_2	53.46	55.58	55.38	54.49	54.70	53.66	53.72	52.01	53.23
Al_2O_3	/0.67	1.65	1.70	1.57	1.80	2.15	1.03	3.90	2.24
Fe_2O_3	1.48	1.34	1.24	.00	0.50	0.85	1.59	—	0.83
FeO	6.68	7.15	7.27	9.20	9.19	12.34	13.84	13.35	15.16
MgO	33.05	32.32	30.69	31.92	30.20	27.47	27.73	27.52	24.60
CaO	2.31	0.74	1.85	1.48	2.22	2.19	1.06	1.97	2.61
Na_2O	0.04	0.03	0.48	tr	0.04	0.07	0.03	—	0.06
K_2O	0.06	0.04	0.22	tr	0.03	0.03	0.00	—	0.01
H_2O	0.54	0.51	0.29	0.15	0.51	0.34	0.52	—	0.58
TiO_2	0.08	tr	—	0.10	0.11	0.12	0.18	—	0.26
P_2O_5	tr	0.10	0.02	0.20	0.02	0.02	—	—	tr
Cr_2O_3	0.38	0.33	0.65	0.64	0.47	0.53	0.30	0.69	0.10
MnO	0.16	0.21	0.21	0.15	0.21	0.23	—	0.56	0.32
	100.00	100.00	100.00	100.00*	100.00	100.00	100.00	100.00	100.00

* NiO 0.10.

3. Enstatite MVL3*a*, Stillwater Complex, Montana. Analyst Phillips. From chromite horizon at Mountain View lake. Large, poikilitic crystals including olivine and chromite. Impurity, a little chromite.

4. Enstatite, Webster, North Carolina. Analyst Phillips. Separated from diopside in Websterite. No impurities.

5. Bronzitite 91, Bushveld Complex. Rock analysis. Analyst C. F. v. d. Walt. Impurities 4.4 per cent plagioclase of approximately An_{56} composition and $\frac{1}{2}$ per cent diopside. Recalculated analysis corrected for these. CaO redetermined by Ellestad on orthopyroxene, free of impurities equals 1.85%. Reference, L. G. Boardman, not published.

6. Bronzitite, Jagdlust, Bushveld Complex. Rock analysis. Analyst H. G. Weall. Impurities 0.20 per cent diopside. CaO redetermined by Ellestad equals 1.48 per cent. Original analysis deficient in this respect. Recalculation somewhat uncertain. Reference: A. L. Hall. The Bushveld Igneous Complex: *Geol. Surv. Union S. Af.*, mem. **28,** 315 (1932).

7. Bronzitite 465E3*h*, Stillwater Complex. Analyst T. Kameda. Rock analysis. Impurities a little chromite and two per cent of olivine approximately Fo_{86}. Corrections for impurities made in recalculated analysis. Some alteration to colorless amphibole. Reference: J. W. Peoples. The Stillwater igneous complex. Ph.D. *thesis*. Princeton University **(1932).**

8. Hypersthene EB32*a*, Stillwater Complex. East Boulder Plateau. Analyst Phillips. Impurities rather high,[5] 5 per cent plagioclase An_{80} and 4 per cent diopsidic pyroxene. CaO redetermined by Phillips on pure material, equals 2.19 per cent. Analysis recalculated minus above impurities.

9. Hypersthenite 374, Bay of Islands Complex, Newfoundland. Rock analysis. Analyst A. Willman. Impurities: some alteration to colorless amphibole (8%), which probably does not alter chemical composition appreciably, and a little chromite and iron sulfide present (2%). Reference: J. R. Cooper: *Newfoundland Dept. Nat. Res. Geol. Sect., Bull.* **4,** (1936).

10. Hypersthene, Johnstown meteorite, Colorado. Analyst E. V. Shannon. No impurities. Reference: E. O. Hovey, *Am. Mus. Novitat,* **203** (1925).

12. Hypersthene, EB43, Stillwater Complex. Analyst R. B. Ellestad. Impurities, less than $\frac{1}{2}$% diopside and labradorite, no correction made in recalculation.

Note: Analyses 7, 9 and 12 made at Rock Analysis Laboratory, University of Minnesota. Analysis 5 published by permission of the Director of the Geological Survey of the Union of South Africa.

OPTICAL PROPERTIES

1. *Determinative methods*

(a) Index of refraction determinations.

As Walls[6] points out the gamma index of orthopyroxenes can be determined with the greatest ease and accuracy, because practically all of the fragments in crushed grains lie on a 110 cleavage face. These are parallel to the *c*-axis and therefore parallel to the direction of the gamma index. The determinations of gamma were made on a temperature-control stage. Curves were made for change in index with temperature for the several immersion liquids used in these determinations. The grains were then mounted on the temperature-control cell and the temperature noted at which the index of the liquid and gamma of the pyroxene were equal. (The liquids were so chosen that little variation from room temperature was necessary.) This can easily be done with an accuracy of $\frac{1}{2}°$ to $\frac{1}{4}°$C. in temperature, or .00025 to .0001 in index. A sodium vapor lamp was used as a source of light for all determinations. The accuracy for the gamma index determinations is certainly better than ±.0005. In any rock, even with complete lack of zoning in the pyroxene, there is a slight variation in composition of various crystals. Determinations must be made on from 6 to 25 grains so that the average will correspond to the analysis. The number of determinations necessary is dependent on the degree of variability of the crystals in a given specimen. A difference in index between two grains, of as little as .0002, can easily be noted in these determinations.

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[5] This was the first specimen separated for analysis. Some plagioclase dust remained in the final separate. The sample should have been washed to remove dust as was done in all other cases. An estimate was made of the amount of dust but it could not be very accurate.

[6] Walls, R., *Mineral. Mag.*, **24,** 165–172 (1935).

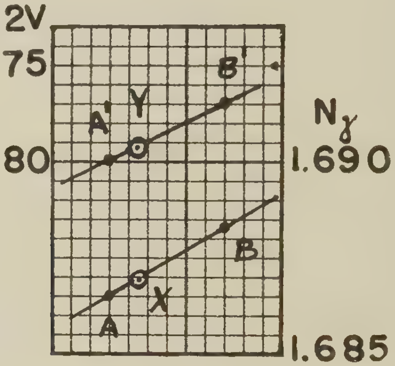

FIG. 1. The lower curve represents the values for the gamma index of refraction with change in composition. Point *X* represents the average value of gamma for a given specimen. Points *A* and *B* indicate the gamma index of two grains from the specimen. Points *A′* and *B′* represent the optic angle of the same two grains. Point *Y* then represents the value for 2V equivalent to point *X* on the gamma index curve, or the average value of 2V for the specimen under consideration.

The alpha and beta indices were not determined directly, since it was found to be far more accurate to determine the index of the direction perpendicular to gamma on the 110 cleavages and calculate the other two principal indices after 2V was determined. The figures for birefringence were also taken from this determination. It is not necessary to make more than two or three determinations of the index perpendicular to gamma, if gamma was determined on the same grains. In this case the gamma found on the grains can be compared to the average value for gamma, and the values alpha and beta adjusted slightly to the value for average gamma along already determined curves, as shown in Fig. 1.

A similar procedure was used in determining the average optic angle to eliminate the necessity of measuring this angle on as many as 25 grains in extreme cases.

(b) Optic angle determinations.

Optic angle determinations were made on a universal stage in sodium light. A grain was rotated until the prism cleavage was north-south. If diopside exsolution lamellae are present it is merely necessary to rotate on the north-south axis until the lamellae are perpendicular, bringing the optic plane perpendicular and Bx_a practically vertical (in the case of enstatite Bx_0). If no lamellae are present the usual universal stage method of grain orientation is employed. After rotating the stage to the 45° position the angle between the optic axis emergence positions (extinction positions) was measured directly. The accuracy of this observation is probably better than $\pm 1°$ for orthopyroxenes.

In the case of enstatite (the Shallowater meteorite specimen) the optic angle had to be determined in thin section, since the angle was small and could not be reached from the prism zone. The determination was not very accurate for two reasons: (1) the birefringence was low so that the extinction position representing the emergence of an optic axis was not very definite. (2) The rate of change of this angle with slight change in composition ($\frac{1}{2}\%$) was so rapid that it was difficult to get a satisfactory average value.

2. *Optical properties and chemical composition*

A number of trial curves were drawn to test the effects of different chemical constituents on the optical properties of the orthopyroxene series. It was found that the variation of properties was controlled almost entirely by the $MgO \cdot SiO_2/Fe(Mn)O \cdot SiO_2$ ratio, and the final curves are based entirely on it.[7] Determination of the gamma index of refraction is the easiest and most accurate method of finding the En:Of ratio of an orthopyroxene. The gamma index value seems to be practically independent of the Al_2O_3, Fe_2O_3, Cr_2O_3, TiO_2 and alkalies contained in the mineral in small but variable amounts. Where lamellae of diopsidic pyroxene are present the CaO is probably contained almost exclusively in the lamellae, so it can have no effect on the optical properties of the orthopyroxene host. Where the lamellae are absent and one to three per cent of CaO is contained in the orthopyroxene, it still does not seem to make an appreciable change in the optical properties, and so may be neglected. With reasonable care the En:Of ratio of an orthopyroxene may be determined from the gamma index with an accuracy of $\pm\frac{1}{2}$ per cent provided a sufficient number of grains are examined to insure that the determination represents a true average for the specimen. Washington and Merwin[8] state that Al_2O_3 and Fe_2O_3 should be considered as present in solid solution in the orthopyroxene and are not present in a separate molecule, such as the Tschermak molecule. The lack of effect of these trivalent oxides, as well as the other oxides mentioned above, with the possible exception of CaO, on the optical properties of orthopyroxenes, suggests that these oxides present in small amounts may merely be included in holes in the crystal lattice and do not themselves form part of the lattice. It is interesting to note that Cr_2O_3 is present in all specimens on which analysis for that oxide was performed, though the amount is small, probably less than one half per cent in all cases except where actual minute inclusions of chromite can be observed. Nickel was determined for only one specimen. Only one tenth of a per cent was found.

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[7] This is in accord with the conclusion reached by Henry for the more iron-rich orthopyroxenes: Henry, N. F. M., *Op. Cit.*

A rapid determination of the En:Of ratio can be made on thin sections without resorting to the slower immersion methods. This can be done by measuring the optic angle, 2V, on a universal stage. The accuracy of this method is about ± one per cent. In certain cases it is unreliable. In the deformed *but not recrystallized* hypersthene-bearing anorthosites and gabbros of the Adirondacks and Labrador many of the orthopyroxenes have abnormally large optic angles, departing by as much as 15° from the curves given in this paper. This appears to be the result of strain in the orthopyroxene. Where the rocks are not deformed or deformed to a greater extent and recrystallized, the optic angles are normal. Many optic angle determinations reported in the literature are high compared to the curve here presented. Though further investigation seems necessary to account definitely for these, all specimens exhibiting an anomalous 2V, which have been examined by the writers, are in such deformed rocks as described above.

A rough test of the accuracy of the optical property determinations and of the inference that the En:Of ratio controls the properties may be made by plotting a curve with 2V in one direction and N_γ in the other (Fig. 3). If it be assumed that the points which are not on the curve are displaced from it because of errors in optical determinations, an error of $\pm.0005$ in gamma and 1° in optic angle would be sufficient to account for those points which are farthest displaced from the curve. The curve itself was drawn by reading values from the N_γ curve and 2V curve in Fig. 2 (this procedure tends to iron out errors of individual determinations and gives a smooth curve) and then plotting the values for individ-

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[8] Washington & Merwin: *Am. Jour. Sci,* **3,** 119 (1922).

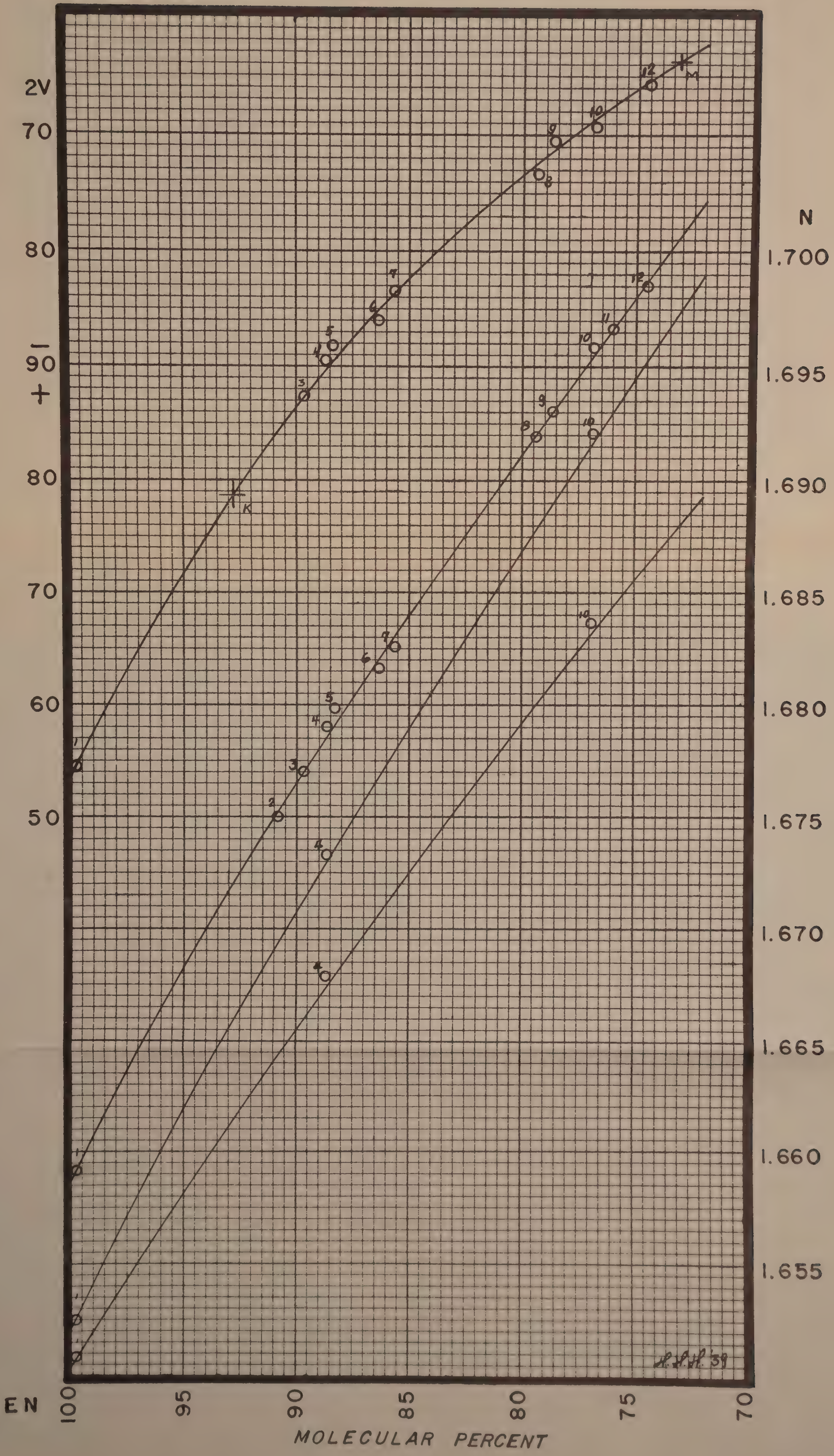
2V
70
80
90
+
80
70
60
50
N
1.700
1.695
1.690
1.685
1.680
1.675
1.670
1.665
1.660
1.655
EN
100
95
90
85
80
75
70
MOLECULAR PERCENT
K
M
1
2
3
4
5
6
7
8
9
10
11
12

Plate I

ual grains on the graph. The points plotted include not only the analyzed specimens but a number of other orthopyroxene specimens, on which 2V and gamma were determined as listed in Table 3. If part of the scattering of points on either side of the curve is due to the effects of minor constituents this effect must be exceedingly small.[9]

TABLE 3

	N gamma	2V	Sign	Occurrence
13. Kupferberger enstatite	1.6719	78.5°	−	P
14. Bonin Islands bronzite	1.6805	87.5	+	V
15. Stillwater St-1 bronzite	1.6821	86	+	P
16. Webster N.C. 2 bronzite	1.6823	85.5	+	P
17. Bushveld 7704 bronzite	1.6820	84.5	+	P
18. Stillwater EB42 hypersthene	1.7010	73.5	+	P
19. Bushveld Pyramids norite 7493 hypersthene	1.7110	53	+	P
20. Stillwater, hornfels? EB89 hypersthene	1.7160	48	+	M
21.[1] Dominica I. andesite ferrohypersthene	1.7210	45.2	+	V
22.[1] Dominica I. andesite ferrohypersthene	1.7214	45.6	+	V
23.[1] Dominica I. andesite ferrohypersthene	1.7221	47.2	+	V
24.[1] Dominica I. andesite ferrohypersthene	1.7240	48	+	V
25.[2] Glen Buchat, contaminated norite, ferrohypersthene	1.731	51	+	P,M
26.[2] Loch Duich ferrohypersthene	1.755	68	+	M
27.[2] Vittinki, eulysite, ferrohypersthene	1.757	70	+	M
28.[2] Tunaberg, eulysite, ferrohypersthene	1.768	81	+	M
29.[2] Mansjö Mt., eulysite, ferrohypersthene	1.769	83	+	M

P = Plutonic igneous rock. M = metamorphic work. V = volcanic igneous rock.

[1] Determinations somewhat less accurate on account of zoning.

[2] Quoted from Henry, *op. cit.*

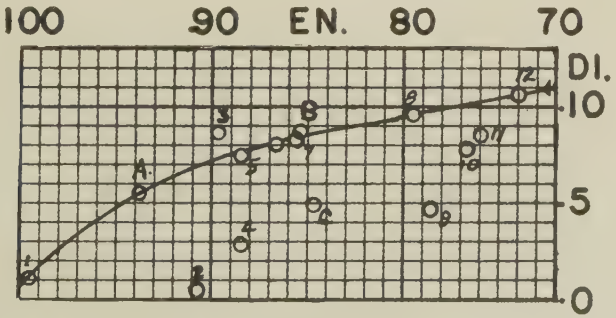

FIG. 2

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[9] Inasmuch as this curve is independent of the composition of the orthopyroxene (no analyses are needed to construct it) it is drawn for the whole known range of these pyroxenes and not limited to the magnesian end of the series.

OCCURRENCES OF ORTHOPYROXENES WITH AND WITHOUT LAMELLAE

Orthopyroxenes of plutonic igneous rocks normally show well developed diopsidic lamellae. In volcanic rocks the lamellae are absent though rare exceptions have been found where they are present to a limited extent. Kuno,[10] for example, has described a phenocryst in a lava from Japan which shows lamellae at its core, the outer portions being free of lamellae. Evidently rapid cooling prevents exsolution of the diopsidic material to form the lamellae. The absence of lamellae is not due to any difference in composition between orthopyroxenes of plutonics and effusives. The lamellae are also present in certain very high temperature hornfelses (perhaps 1000°C.) such as those found along the floors of the Stillwater Complex and the Duluth gabbro. In other metamorphics, as for example the recrystallized hypersthene-bearing rocks of the Adirondacks, no lamellae are found. In this case the absence of lamellae cannot be due to rapid cooling. It seems more likely that the metamorphic recrystallization, during which the hypersthene was formed, took place at a temperature below the level at which diopside is appreciably soluble in

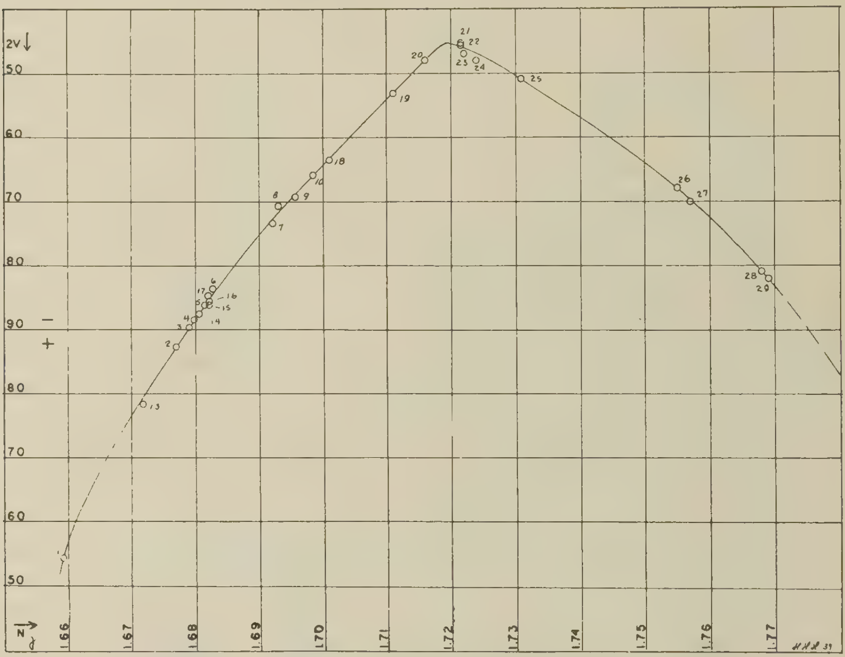

FIG. 3

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[10] Kuno, H., *Proc. Imp. Acad. Tokyo*, **14**, 218 (1938).

hypersthene. If this is true the hypersthene should have little or no CaO. No chemical analyses are available at present to check this conclusion. There is, however, a considerable body of indirect evidence to support the hypothesis.

The enstatites and bronzites of many ultramafic igneous rocks of the type which Hess has suggested are derived from an ultramafic magma have lamellae. In many (but not all) cases these orthopyroxenes have conspicuously fewer lamellae than normal and some of the chemical analyses (numbers 4 and 9) show a deficiency of CaO as compared with the orthopyroxenes of other plutonics (Fig. 2). This may result from the fact that the magma has very little CaO. In those cases where little orthopyroxene is present there may be enough CaO to permit the usual amount of CaO to go into the pyroxene, but where a greater amount of orthopyroxene is present there may be a deficiency in CaO so orthopyroxenes with few lamellae may result.[11]

In orthopyroxene-bearing rocks intruded at shallow to moderate depths, lamellae may or may not be present. As a rule a poor development of lamellae has been noted. These lamellae are less regularly distributed through the crystal and tend to be more irregular in form than in the plutonics. In the plutonics they resemble fine, straight, ruled lines when the 010 face of a crystal is examined under crossed nicols. In the hypabyssal rocks some "lines" which are less regular and some oriented globs or quadrilateral areas of diopsidic pyroxene may be seen, and all these are mainly confined to the cores of the crystals.

The writers have noted orthopyroxenes with well-developed lamellae in rocks of the following localities: Stillwater Complex, Montana; Bushveld Complex, South Africa; Bay of Islands Complex, Newfoundland; Baltimore gabbro, Maryland; high temperature hornfels along the floors of the Stillwater Complex and Duluth gabbro; pegmatite, Roseland, Virginia; anorthosites and gabbros, Labrador; peridotites of Cuba and the Appalachians; and the anorthosites and gabbros of the Adirondacks (not recrystallized) and norites of the Harz Mountains.

Orthopyroxenes without lamellae were noted in the following localities: Lesser Antilles volcanics; Bonin Islands volcanics; trachytes, Hungary; porphyries, Harz Mountains; recrystallized rocks of the Adirondacks and pyroxene granulites of Saxony. Poorly developed lamellae are present in the Palisades diabase orthopyroxene. (This sill was intruded into Triassic sediments in Triassic time. Its depth could not have been more than two or three miles from the surface at a maximum.)

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[11] Crystallization of the magma at a low temperature would also account for the lack of CaO in the orthopyroxene since less diopsidic material would be soluble in the orthopyroxene.

The hypersthene andesites of Tokaj, Hungary, show an incipient development of lamellae.

PETROLOGIC APPLICATIONS

Orthopyroxenes without lamellae are present in volcanic igneous rocks and in certain metamorphic rocks recrystallized at high temperatures (probably in the neighborhood of 600°C.). In the first case the lamellae are absent because rapid cooling has prevented exsolution of the diopsidic material contained in them. A large number of chemical analyses available in the literature show that the diopsidic content of these orthopyroxenes is the same as those which do have lamellae. In the second case mentioned above, certain high temperature metamorphic rocks, the absence of lamellae is presumably the result of recrystallization of orthopyroxene at a temperature below which diopside is soluble in hypersthene. These should contain little or no diopsidic material.

The presence of hypersthene without lamellae in the heavy mineral concentrates of sediments, particularly if the grains show traces of original crystal outlines, is almost certain proof of a source of the sediments from an area at least partly covered by volcanics. The metamorphic hypersthenes without lamellae are relatively rare and seldom show crystal outlines. They are generally irregular anhedral grains. A test for CaO might distinguish between the two varieties, but as a rule geologic relations in the possible source areas will rule out one type or the other so that there is little chance for confusion. This criterion for distinguishing a volcanic source is important because none of the other minerals common in sedimentary heavy mineral suites is diagnostic of volcanics. In present day sediments hypersthene makes up roughly half of the heavy mineral suite of beach sands of the Lesser Antilles volcanic islands. It has been used successfully to indicate a partly volcanic source in various Tertiary sediments in the Caribbean region by one of the present authors.

The fact that stony meteorites contain orthopyroxenes without lamellae and that analyses of them prove that dissolved diopside is present (7.8 per cent in the Johnstown meteorite, analysis above) indicates rapid cooling of meteorites analogous to that of volcanics.

ORTHOPYROXENE NOMENCLATURE

In view of the more precise optical data now available a revised nomenclature for members of the enstatite-orthoferrosilite series is suggested on the opposite page.

Optically positive	$\mathrm{En}_{100}-\mathrm{En}_{88\frac{1}{2}}$	Enstatite
Optically negative	$\mathrm{En}_{88\frac{1}{2}}-\mathrm{En}_{80}$	Bronzite
	$\mathrm{En}_{80}-\mathrm{En}_{50}$	Hypersthene
	$\mathrm{En}_{50}-\mathrm{En}_{12\pm}$	Ferrohypersthene
Optically positive	$\mathrm{En}_{12\pm}-\mathrm{En}_{0}$	Orthoferrosilite

RELIABLE AND RAPID METHOD FOR DISTINGUISHING QUARTZ AND UNTWINNED FELDSPAR WITH THE UNIVERSAL STAGE*

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Abstract

A reliable and rapid method is described for the determination of quartz and untwinned feldspar in mineral grains or thin sections by means of the universal stage. The orthoclase-albite and oligoclase-anorthite groups can be determined simultaneously by the Becke-line method.

The determination of a hundred grains can be made in about 30 minutes. Only turbid (altered) feldspar is difficult to determine, but may be counted as a separate group.

1. Introduction

The counting of mineral grains is coming to be more and more generally adopted in sedimentary petrological studies. An accurate and rapid method for determining the light fraction minerals, quartz and feldspar, has however, not yet been described.

The various varieties of feldspar can be easily distinguished by the use of immersion liquids. Distinguishing quartz from untwinned oligoclase-andesine, which has the same refractive indices (1.544–1.553), has caused many difficulties. Staining methods have been suggested by many authors (3, 8, 9). According to Holmquist (9) these methods are not reliable for Ca-free feldspar. CaF_2 seems to be strongly absorptive to dyes, but NaF and KF are less so. The soda and potash fluorides, furthermore, are soluble in water. Albite from geodes and adularia cannot be stained and microline is not, or only partly, colored (9).

The distinction between quartz and feldspar with the universal stage has not received the attention it deserves. In 1931 the main outline for the determination of uniaxial and biaxial minerals by this method was clearly given by Reinhard (11). In most handbooks of mineralogy the determination of uniaxial minerals by means of the universal stage is generally omitted as being useless. Dodge (4) is the first author to call attention to the universal stage for the determination of the quartz content of quartz-feldspar mixtures. His description of the manner in which quartz can be distinguished, however, is inadequate. Ingerson (10) gives a more complete description, but his method is so complicated that it is not likely to be used in actual practice. It is furthermore not always conclusive and cannot be used for mineral grains.

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As the necessary manipulations cannot be understood without a thorough knowledge of the optical properties of uniaxial and biaxial minerals a brief summary of these data is here recorded.

Two groups of feldspar which have refractive indices above and below that of Canada balsam (about 1.535), or some other mounting medium, can be distinguished simultaneously by the Becke method. The determination of turbid grains remains difficult. If many such grains are present a study has to be made of the different stages of alteration which causes the turbidity. If the nature of the turbid grains cannot be determined in this way they may be counted as one group of "turbid" feldspar.

Rock particles are also characteristic components of certain groups of sediments (1) and should be distinguished and counted in the same way as the mineral grains. The time required for counting 100 grains of a quartz-feldspar mixture is about 30 minutes. The counting of 100 grains is more than sufficient as generally less than 5 mineral species with practically the same specific gravity must be distinguished. If a series of rock samples from one formation must be investigated, the determination of only 50 grains per slide will be sufficient. Changing slides on the universal stage takes less than 5 minutes.

The method has been tried out in the sedimentary petrological laboratory of the N. V. De Bataafsche Petroleum Maatschappij in Amsterdam. We wish to express our gratitude to Dr. W. J. Jong for his friendly criticism.

2. The Universal Stage

The universal stage (with 4 axes) provided with a mechanical stage (Fig. 1) which was used in Amsterdam, was manufactured by Leitz and fitted on a Leitz polarizing microscope, model KM. The axes on which the different parts of the universal stage can be rotated have been variously labelled by different authors.

Emmons and Reinhard use letters, which is confusing, as the meaning of these symbols is not universally understood. Numbers are more practical. Berek and Winchell, however, have numbered the axes in different ways. Berek (2) indicates the vertical rotation axis of the inner stage with I. Winchell (12) gives I to the microscope axis and V to the vertical axis of the inner stage. Using the notations of Winchell, the E-W axis of the inner ring of the modified universal stage (Emmons, 5) can be indicated by VI. If it is desirable, for special purposes, to add more rotation axes, these could be labelled with higher figures, always giving odd numbers to vertical and even to horizontal rotation axes.

Winchell (12) uses a different sequence of numbers for the axes of the modified universal stage than for those of the stage with four axes. This

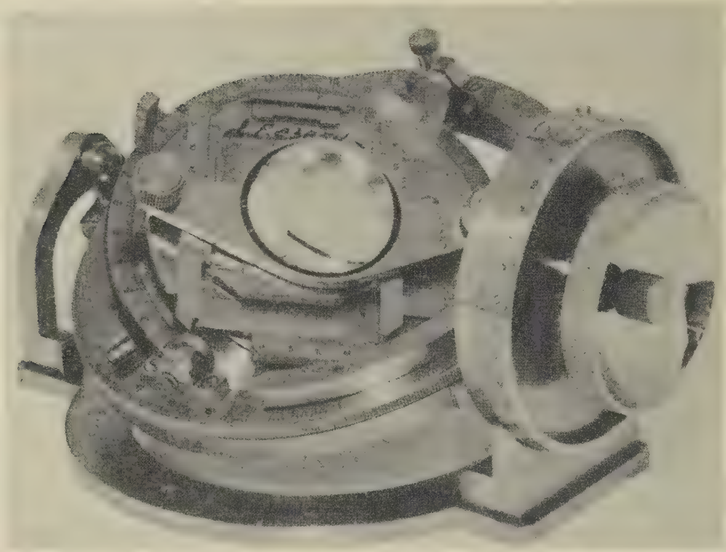


FIG. 1

is confusing. Figure 2 shows a diagram of the stage with the notations of the axes which are used in this paper. For convenience these will be compared with those used by Berek, Reinhard and Emmons (2, 5, 11).

Berek	Reinhard	Emmons	This paper and Winchell	
V	M	M	I	= vertical rotation axis of the stage of the microscope on which the universal stage is attached.
IV	K	O.E-W	II	= horizontal rotation axis of the outer ring of the universal stage. This axis should be in the E-W position.
III	A	O.V.	III	= vertical rotation axis of outer ring.
II	H	N-S	IV	= horizontal rotation axis of inner stage. This axis must be normal to II in the zero position.
I	N	I.V.	V	= vertical axis of inner ring.
		I.E-W	VI	= horizontal E-W axis of inner stage of the modified universal stage. This axis should be parallel to II.

The adjustment of the universal stage is described by Berek, Reinhard and Winchell (2, 10, 12). For our purpose careful adjustment is not necessary. The vertical axis of the inner ring should be properly centered and the stage of the microscope should be fixed with the axes II, IV and VI of the universal stage parallel to the vibration directions of the nicols (E-W, N-S and E-W, respectively). This position with the inner and outer stages of the universal stage parallel to the table of the microscope will be called the "zero position" of the universal stage (Fig. 2).

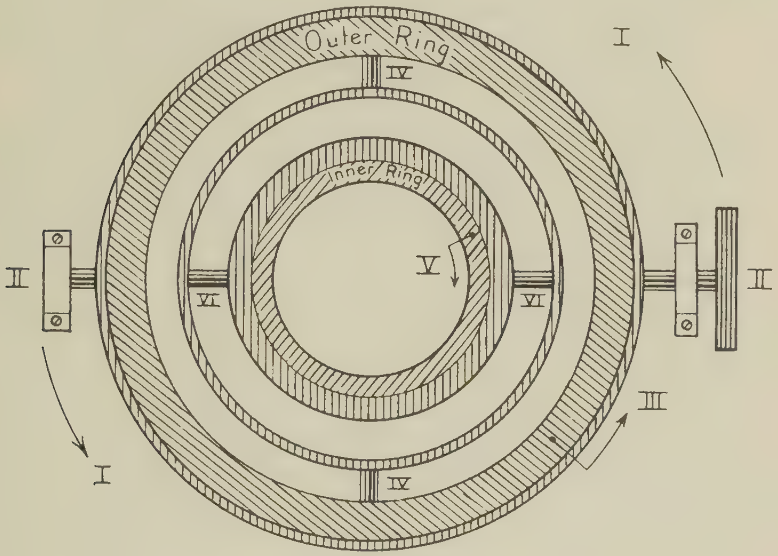


Fig. 2

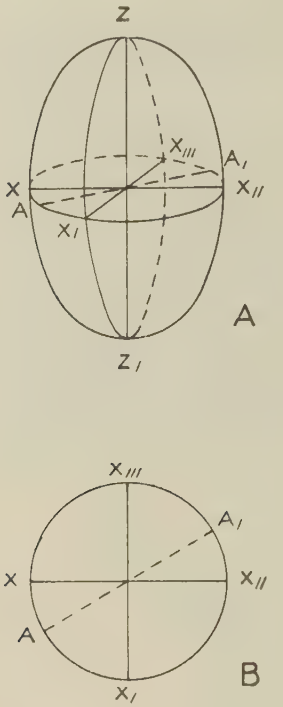
3. Theory of Distinction Between Uniaxial and Biaxial Minerals

The distinction between quartz and feldspar by means of the universal stage is based on the difference in shape of the indicatrices of uniaxial and biaxial minerals. The indicatrix of a uniaxial mineral is an ellipsoid of rotation and that of a biaxial mineral a triaxial ellipsoid (Figs. 3 A, B; and 4 A, B).

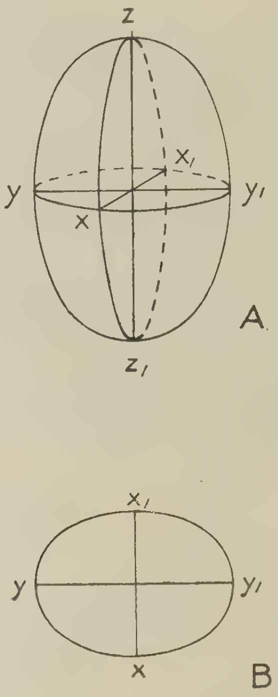
The method is based on three facts:

1. A mineral remains in extinction when rotated on a horizontal axis (II, IV or VI) only when a symmetry plane of the indicatrix is normal to this axis.
2. Uniaxial minerals have an infinite number of optical symmetry planes parallel to the optic axis and one plane of optical symmetry normal thereto (Figs. 3 A and B).
3. Biaxial minerals have only three planes of optical symmetry which are perpendicular to each other (Figs. 4 A and B).

Those sections through the indicatrix which are important in distinguishing between uniaxial and biaxial minerals will be dealt with separately.



Figs. 3. A and B. Indicatrix of uniaxial mineral; $XX_{11}=X_1X_{111}=AA_1$.



Figs. 4. A and B. Indicatrix of biaxial mineral; $XX_1<YY_1$.

A. Uniaxial Minerals

1. *Optic axis perpendicular to the inner stage*

The mineral remains in extinction by rotation of V (vertical axis of inner stage). The mineral also remains in extinction by turning II or IV from "zero position," as one of the many planes of symmetry parallel to the optic axis always remains parallel to the planes of vibration of the nicols.

2. *Optic axis parallel to the inner stage*

If the mineral is brought to extinction by rotating V, the optic axis and the plane of symmetry normal to the optic axis are parallel to the planes of vibration of the nicols. Rotation of II or IV from the zero position does not disturb the extinction, as a plane of symmetry remains parallel to the vibration directions of the nicols. If, in this case, the optic axis is parallel to IV (N-S), the inner stage can be inclined by rotation of IV without changing the extinction. It is important for the distinction between uniaxial and biaxial minerals, however, that subsequent rotation of II does not disturb the extinction. Rotation of IV (optic axis is parallel to IV) only brings another optic plane of symmetry normal to II. If the mineral were biaxial the grains would depart from extinction.

3. *Optic axis inclined towards the inner stage*

If the mineral is brought to extinction by V, the optic axis (and one of the symmetry planes parallel to it) is always parallel to the vibration plane of one of the nicols. If the axis perpendicular to this plane is rotated, extinction remains. The mineral departs from extinction if the other horizontal axis is turned. The optic axis is inclined to this axis and moves out of the vibration direction of the nicols. If the latter rotation axis were IV and were rotated 30°, the extinction of the mineral could be restored by rotation of V (vertical axis of inner ring). The optic axis will again be parallel to the N-S vibration plane of the nicols and subsequent rotation of II does not disturb the extinction (a biaxial mineral would depart from extinction). This holds only if the optic axis is normal to II. If the optic axis is parallel to II, V should be rotated 90° in order to bring it normal to II. This is not necessary when the modified stage is used. The inner table should then be inclined by VI. The extinction should be restored by V, followed by rotation of IV instead of II.

B. BIAXIAL MINERALS

1. *Optic axis normal to the inner stage*

The mineral remains practically at extinction by rotating the vertical axis of the inner stage. The mineral, however, remains at extinction by rotation of II or IV from zero position only if the plane of the optic axes (one of the three planes of symmetry of the triaxial indicatrix) is parallel to the plane of vibration of one of the nicols. (Uniaxial minerals in this position remain at extinction by rotation of either II or IV.)

2. *An axis of symmetry of the triaxial ellipsoid is perpendicular to the inner stage*

Two planes of symmetry (Fig. 5 A, ZXZ_1X_1 and XYX_1Y_1) are perpendicular to the inner stage and will be normal to II and IV, if the mineral is turned to extinction by V. The rotation of II or IV from zero position does not disturb the extinction as the plane of symmetry normal to the axis of rotation remains parallel to the plane of vibration of one of the nicols. After inclination of the inner table by IV, however, rotation of II always disturbs the extinction. This distinguishes uniaxial from biaxial minerals. The reason is explained under 3.

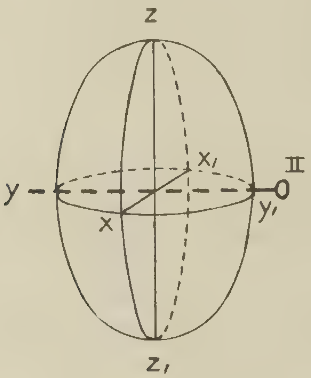


FIG. 5A

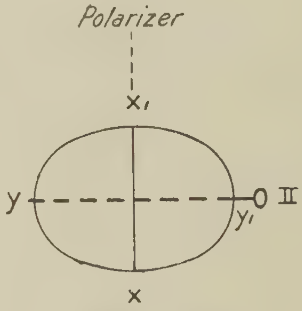


FIG. 5B

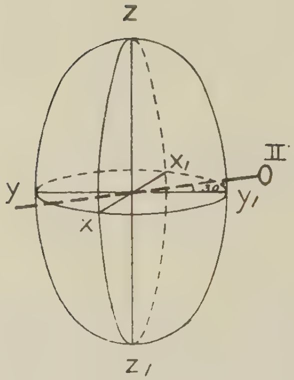


FIG. 6A

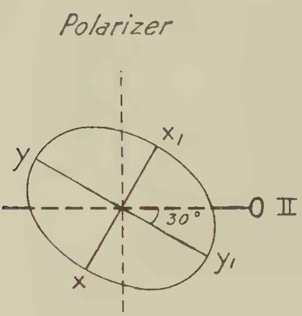


FIG. 6B

3. *Three planes of symmetry of the triaxial indicatrix are inclined towards the inner stage*

If the mineral is brought to extinction by rotation of V, none of the planes of symmetry are parallel to the planes of vibration of the nicols. Only the axes of a sectional ellipse which gives the vibration directions of the ray perpendicular to this section are parallel to the cross-hairs of the microscope. By rotation of II or IV from the zero position the mineral always departs from extinction. This is very difficult to explain and therefore only a simple case will be cited. For instance, if in the zero position of the stage ZZ_1 were parallel to IV (N-S) and YY_1 were inclined 30° to II (Fig. 6A), the mineral would be extinguished as the optical plane of symmetry XYX_1Y (Fig. 6A) is parallel to the E-W vibration plane of the nicols. If II could be rotated 90° (Fig. 6B) the axis YY_1 and XX_1 would make an angle of 30° with the cross-hairs. The mineral would then not be in position of extinction. The rotation from the zero position to the 90° position of II corresponds to a gradual departing from extinction. If II had been rotated only 45° and the mineral then brought to extinction by rotation of V, the mineral would again depart from extinction by rotation of II. This phenomenon can be seen when a small model of a triaxial ellipsoid is placed on the universal stage with none of the axes of optical symmetry parallel to the axes of the stage.

The above data can be summarized as follows:

A. Uniaxial Minerals

If the optic axis is perpendicular to II, rotation of II never disturbs the extinction. By rotation of IV the mineral only remains at extinction if the optic axis is parallel to the inner stage. When the inner table has been inclined 20°–60° by rotation of IV and the mineral is brought to extinction by V, with the shortest interval, rotation of II again does not disturb the extinction.

Mineral sections that are normal to the optic axis (remain dark on rotating V) always remain at extinction on rotating II or IV.

B. Biaxial Minerals

Biaxial minerals remain at extinction only if an axis of the triaxial indicatrix is parallel to a horizontal axis of the stage. If a biaxial mineral, which remains extinguished on rotating II, is inclined 20°–60° by IV and the extinction has been restored by rotating V, it no longer remains at extinction on rotating II.

Mineral sections which are normal to an optic axis remain at extinction by a rotation of horizontal axes only when the plane of the optic axes is normal to this axis.

4. *Manipulations for the determination of the quartz-feldspar ratio with the universal stage*

The determination of each grain generally starts from the zero position of the universal stage. By rotation of V the exact extinction position of minerals which have a low birefringence color (sections nearly normal to an optic axis) is sometimes difficult to find. In such cases it is better to start with the inner table inclined at 40° by rotation of IV.

The distinction between quartz and feldspar is carried out as follows:

1. *Determination of refractive index*

The refractive index of the grain is determined by the Becke-line method. If the refractive index is below that of Canada balsam (about 1.535) the grain is not quartz and is probably feldspar (orthoclase-microcline-albite). If the refractive index is equal to or higher than 1.535, it may be quartz, feldspar (oligoclase-anorthite) or muscovite, etc.

Minerals other than quartz and feldspar can generally be recognized by their shape, refractive index and birefringence.

2. *Determination with the universal stage*

The following manipulations should be applied only for the determination of untwinned feldspar with a refractive index higher than 1.535. If the manipulations are simpler with the modified universal stage (5), the axes which should be used instead are given in brackets following those used for the stage with 4 axes.

MANIPULATION	EXPLANATION
A. *MINERAL REMAINS AT EXTINCTION DURING ROTATION OF V.*	Optic axis is normal to plane of inner stage.
II is rotated 40° to each side:	
1. If mineral does not remain at extinction it is biaxial.	Unaxial minerals always remain in extinction by rotation of II or IV if optic axis is normal to the stage (page 290, A1).
2. If mineral remains at extinction, II is brought to zero and IV is rotated about 40° to either side. If the mineral again remains at extinction, it is uniaxial, if not, it is biaxial.	Rotation of IV is necessary as the mineral could still be biaxial with the plane of the optic axes normal to II (page 291, B1).
B. *THE MINERAL IS BROUGHT TO EXTINCTION BY ROTATING V.*	
II is rotated about 40° to both sides and returned to zero position. Afterwards IV is rotated 40° to each side.	
1. If the mineral does not remain at extinction in both cases, it is biaxial.	A uniaxial mineral remains at extinction during at least one of the two rotations (page 291, A3).
2. The mineral remains extinguished only after rotation of IV. II and IV are returned to zero position.	
Inner table is rotated 90° by V. The mineral now remains at extinction only by rotating II. If a modified stage is used this manipulation is not necessary. The notations of the axes	For determination of uniaxial minerals on the stage with 4 axes, the optic axis must be normal to II (page 291, A3).

Manipulation	Explanation
to be used in this case under 3 are placed in brackets following those for the old type of stage.	
3. Mineral remains at extinction only by rotation of II {IV}.	Optic axis of uniaxial mineral is perpendicular to II {IV}, but not parallel to IV {VI}.
Inner ring is inclined about 40° by rotating IV {VI}.	Mineral does not remain at extinction.
Mineral is brought to extinction in this position by rotating V over shortest interval. Now II {IV} is rotated 40° to each side.	If uniaxial: optic axis is again brought normal to II {IV} and a plane of symmetry of the indicatrix will remain parallel during rotation of II {IV} (page 291, A3).
If the mineral remains at extinction it is uniaxial, if not, it is biaxial.	If biaxial: one of the three planes of optic symmetry which has been normal to II now is inclined 40° to II (page 292, B3).
4. Mineral remains dark in both cases.	A plane of symmetry of the indicatrix is parallel to the inner stage (page 290, A2 and page 292, B2).
II is returned to zero position and the inner stage is inclined at 40° by rotating IV. Then II is rotated 40° to each side.	If biaxial, the plane of symmetry which was normal to II, now is inclined 40 to II and the mineral should not remain extinguished during rotation of II.
If mineral remains at extinction it is uniaxial.	A uniaxial mineral remains at extinction by rotation of at least one of the horizontal axes (page 290, A2).
If the mineral does not remain extinguished, II and IV are brought back to zero position. V is rotated 90°. (For modified stage this is not necessary. Use notations in brackets.)	Mineral still may be uniaxial if optic axis originally has been parallel to II. Rotation of V over 90° in zero position brings optic axis parallel to IV and normal to II. Further explanation is similar to that of 3.
Now IV {VI} is inclined 40° and II {IV} is rotated 40° to each side.	
If mineral remains at extinction, it is uniaxial, if not, it is biaxial.	For uniaxial minerals, see page 290, A2. For biaxial minerals see page 291, B2).

The latter case is the most complicated, but is rare, as it occurs only when a plane of symmetry of the indicatrix is parallel to the inner stage.

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NOTES AND NEWS

DISCUSSION OF "THE FORMULA OF JORDANITE"

D. JEROME FISHER, *University of Chicago, Chicago, Illinois.*

Richmond[1] has suggested alternative new formulae for jordanite, calculations from which do not satisfactorily fit the observed density. In recent correspondence he has stated his density value of 6.32 is probably too low, because of inaccuracies in his method. At his suggestion and my request Dr. Harry Berman of Harvard University kindly determined the density of one of the crystals (weight 11.83 mg.) used by Professor Palache, and obtained the value 6.38 ± 0.01. Since Jackson determined the density of but one of his samples analyzed (Table 1, column 1), and since that was the one richer in lead, it may be assumed tentatively that the material on which he ran his other analysis had a density of about 6.38 (column 2). Columns 3 and 4 show the resulting calculated cell contents. If M_0 be taken at an intermediate value, calculations on the analysis of column 1 lead to the results shown in column 5 with 44 atomic positions in the unit cell. These can most reasonably be distributed as $Pb_{14}As_7S_{23}$. The composition calculated from this formula is shown in column 6. It does not fit the analyses as well as does Richmond's preferred formula (column 7), but it probably lies within the

TABLE 1

	1	2	3	4	5	6	7
Pb	69.22	69.03	13.75	13.64	13.7	69.69	69.20
As	12.42	12.50	6.82	6.83	6.8	12.60	12.46
S	18.36	18.47	23.57	23.59	23.5	17.71	18.34
Totals	100.00	100.00	44.14	44.06	44.0	100.00	100.00
D	6.413	6.38 ± .01			6.39	6.49	6.54
M_0	4115	4094			4102	4163	4195

1. Analysis of jordanite from Binnenthal by Jackson, recalculated from 99.12 to 100%. V_0 value assumed as 1058.
2. Analysis of jordanite from Binnenthal by Jackson, recalculated from 99.71 to 100%. V_0 value assumed as 1058. Density value given is that determined by Berman.
3. Atomic content of unit cell from #1.
4. Atomic content of unit cell from #2.
5. Atomic content of unit cell from #1 assuming $M_0 = 4102$.
6. Calculated composition of $Pb_{14}As_7S_{23}$ (Fisher).
7. Calculated composition of $Pb_{14}As_7S_{24}$ (Richmond).

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[1] Richmond, W. E., this journal, **23,** 830 (1938). In Table 3 the density for Pb_4As_2S- should be 6.56, not 5.63.

limits of analytical errors. Consideration of observed versus calculated compositions for $Pb_{14}As_7S_{23}$ indicates that 2.1% of the S occupies some of both the Pb and As positions of the Binnenthal jordanite; this is not unreasonable, since the S atoms are smaller than the others. Making these assumptions, the calculated density of jordanite (column 5) agrees well with the observed values. Since the molecular weight of $Pb_{14}As_7S_{24}$ is 4195, whether computed just from a table of atomic weights or from Jackson's analysis (column 1) taking M_0 at a value such that there are just 45 atoms in the unit cell, there is no possibility of assuming replacements in Richmond's formula that would make the calculated density of 6.54 check the observed value.

The formula $Pb_{13}As_7S_{23}$ (Richmond's second choice) is definitely unsatisfactory, not only because of the discrepancies in molecular weight and density, but also because it would seem to demand that part (3.0%) of the large Pb atoms occupy the positions of the distinctly (say 18%) smaller As; moreover it does not very satisfactorily represent the chemical analysis. This raises the question of whether jordanite and meneghinite[2] can be dimorphous. The writer agrees with Richmond that this cannot be answered on the basis of published data; new experimental work is required to substantiate or disprove the suggested new formulae of both minerals. The available data on meneghinite are too unsatisfactory to yield to the sort of analysis here applied to jordanite.

Summary. The old formula of jordanite ($Pb_4As_2S_7$) is equivalent to $Pb_{14}As_7S_{24\frac{1}{2}}$. Richmond proposed that the S value be decreased to 24. Because of the reasons given above, the writer suggests that 23 S more probably represents the ideal crystal.

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[2] *Ibid.*, p. 827.

NOTES ON REFRACTIVE INDEX LIQUIDS

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Butler (1) described a set of immersion liquids of intermediate refraction using a kerosene fraction and α-monochlornaphthalene. The fractionation is briefly discussed, but with the exception of stressing the fractionation ranges and the need to redistill, few details are given for the preparation of this paraffin mixture. In this short note I intend to show that redistillation is unnecessary, that the preparation is comparatively simple and that liquids prepared in this way are stable for a period of years.

1. *Fractionation of paraffin*

It was found that only the finest grade of illuminating paraffins or kerosenes yielding distillates having a fairly pleasant odour were of any value. Many were tried and those giving fractions of unpleasant odour almost invariably gave sulphurous, gelatinous precipitates on mixing with the naphthalenes.

The process was carried out in an ordinary distilling flash with Liebig condenser attached. In Table 1 the refractive indices of a satisfactory kerosene are given, together with the indices of the various fractions. In Table 2 some data on the yields of several liquids are given.

Table 1

N_d of original kerosene = 1.4466 at 23.2°C.

Fraction	N_d	
below 150°	1.4288	
150–170°	1.4324	
170–190°	1.4360	
190–210°	1.4409	
210–220°	1.4443	23°C.
220–230°	1.4478	
230–240°	1.4502	
240–250°	1.4555	
residue	1.4569	

Table 2

Sample No. 1

N_d of sample = 1.4373 at 14.3°C.

Fraction	% by volume	N_d	Temperature °C.
150–210°	59.2	1.4319	14.5
210–240°	32.6	1.4413	14.5
$\between$240°	7.3	1.4502	14.5
	99.1		

SAMPLE NO. 2

N_d of sample=1.4453 at 20.7°C.

140–210°	38.2	1.4369	25.7
210–240°	29.8	1.4471	21.8
Residue	30.9	1.4553	25.7
	98.9		

TABLE 3

Fraction	% by volume	N_d	Temperature °C.
210–240°	29.8	1.4471	21.8
210–240°	30.7	1.4473	26.0
210–240°	31.0	1.4464	26.0
220–250°	32.0	1.4501	26.5
210–250°	36.5	1.4498	22.8

In the case of sample 1 it was found that even redistilling the 210°–240° fraction and using only the 210–230° portion, the liquid had a very pungent odour, although it was colourless. This sample was found to be quite unsatisfactory.

Work was confined to sample 2 and the results of five distillations are given in Table 3. These distillates were finally combined and used in making up several sets of liquids.

The 210–250° fractions were found to be miscible in all proportions with α-chlornaphthalene and α-bromnaphthalene and phenyldiiodoarsine, giving colourless to pale yellow and yellow liquids in the first two cases and reddish brown in the third case. However, different samples of phenyldiiodoarsine (R.I. 1.8496 at 20°C) had different colours, some were canary yellow and one sample a rather deep red. Apparently the lighter colour is the purer and was found to be more stable. At a later date, however, it is hoped to investigate this more fully.

2. *Stability of liquids*

Results are available for two sets of liquids, one the kerosene fraction —α-chlornaphthalene, and another kerosene fraction—α-bromnaphthalene. From many observations, the ideal set of liquids for the range 1.44 to 1.85 is kerosene fraction—α-bromnaphthalene—phenyldiiodoarsine. The latter is rather expensive but the greater stability, lower dispersion and lower colour intensity compared with other liquids more than offsets the high initial cost.

In table 4 the observations over nearly three years are given. No adjustments were made at any period, for accurate work aliquot proportions being removed and corrected to the refractive index required. Moreover the liquids were kept in transparent bottles and no precautions

TABLE 4

Nominal Refractive Index	Prepared			Tested			Tested		
	Date	N_d	Temperature	Date	N_d	Temperature	Date	N_d	Temperature
1.45	May 1936	1.4503	18°C.	3-6-36	1.4511	18°C.	4-10-39	1.4512	19°C.
1.47		1.4703	18°C.	3-6-36	1.4711	18°C.		1.4711	19°C.
1.50		1.5001	18°C.					1.5006	19°C.
1.54		1.5399	18°C.	3-4-38	1.5409	19°C.		1.5408	19°C.
1.57	June 1937	1.5697	19°C.	3-6-36	1.5675	—		1.5688	19°C.
1.60		1.6004	19°C.	3-6-36	1.6029	18°C.		1.6025	19°C.
1.62		1.6205	15.5°C.	3-4-38	1.6175	19.5°C.		1.6191	19°C.
1.66	September 1937	1.6585	15.5°C.	3-4-38	1.6588	19°C.		1.6568	19°C.

Note. Liquids of higher refractive index were made up, but the record only extends over a few months.

were taken against light. The higher liquids are not as stable as the α-chlornaphthalene (and α-bromnaphthalene)—kerosene series, but this may be due to the inferior quality of some of the phenyldiiodoarsine. As the paraffin is miscible in all proportions with the phenyldiiodoarsine these two liquids should suffice for a set of immersion oils. The napththalenes were only used as a measure of economy.

I am indebted to Mr. E. Mendelssohn of the Department of Geology, University of the Witwatersrand, for encouragement to undertake this work when I was a student in that department.

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COLOR BLINDNESS AMONG STUDENTS OF MINERALOGY

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In teaching determinative mineralogy, the writer tries to impress upon the student the need of correctly identifying the properties exhibited by the specimen being determined. To facilitate checking the student's determinations, the writer provides each student with an outline form on which he writes the properties as he determines them in tracing down the mineral. In checking these sheets with the student, the writer discovered that certain ones made gross errors in identifying color and streak. While some errors of this type were due to a lack of color training, an appreciable number were found to be due to color blindness. This has led the writer to test every student in mineralogy for this eye defect soon after he enters the course.

For several years a numbered set of minerals covering the chromatic range were used with a multiple-choice type of question. The student simply had to select the correct color name for each specimen. It was found, however, that this test did not distinguish color blindness from color ignorance, and for the past few years the Ishihara test has been used.[1] This test simply requires the student to read a number. It is accurate and requires less than one minute per student.

According to Ishihara, 5 per cent of all males are color-blind. Females are rarely afflicted but are responsible for the transmission of the defect. The classes taught by the writer are composed only of males and the incidence of color blindness as determined by the Ishihara test is indicated in the following table:

Table 1

Color Blindness Among Students of Mineralogy at Missouri School of Mines

Year	Students		
	Total number tested	Color-blind	
		Number	Per cent
1937	56	3	5.36
1938	87	4	4.59
1939	72	7	9.72
Total	215	14	6.60

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[1] Ishihara, Shinobu, *Tests for Colour-Blindness*, Kanehara and Co., Tokyo, Japan. (U.S. Agent: C. H. Stoelting Co., 424 North Homan Ave., Chicago, Illinois.)

All fourteen students found to be color-blind have the common red-green type of congenital color blindness. Of the seven found to be color-blind in 1939, four are green-blind, one is red-blind and two are incompletely red-green blind. The completely green-blind confuse green and purple with gray, the completely red-blind confuse red and bluish green with gray. The incompletely red-green blind have difficulty with certain red and green tints and shades while others can be distinguished.

The most interesting result of the test is that it reveals color blindness in individuals who did not know that they were afflicted. For example, of the seven color-blind in this year's classes only one definitely knew that he was afflicted. He had been tested before. Another knew that he could find a yellow wooden tee when playing golf but had difficulty in recovering a red one. The other five were not aware of their eye defects until they were tested in the mineralogy class. To these the test is helpful, for although nothing can be done to correct this defect, awareness of being color-blind is apt to make one more cautious where color is concerned. In determining minerals he will rely less on color and streak and more on other properties. The test also is of value to the instructor, for he becomes aware of the handicap under which some of his students work, and he is likely to be more tolerant toward them. The writer believes that the administration of this test is well worth the little time it takes and recommends it especially to instructors whose classes are so large that they cannot give the individual much personal attention.

RADIOACTIVE STANDARDS*

A series of radioactive standards are being prepared under the direction of the Committee on Standards of Radioactivity of the National Research Council. These standards will be deposited at the National Bureau of Standards in Washington, D. C. to be issued as working standards to investigators who may desire them.

The standards under preparation at present are:

1) Radium Standards
   a) 100 cc. solutions sealed in 200 cc. pyrex flasks containing 10^{-9} and 10^{-11} grams of radium to be used as emanation standards either directly or by subdilution.
   b) 5 cc. solutions sealed in pyrex ampoules containing 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10, 20, 50 and 100 micrograms of radium to be used as gamma ray standards. If desired, these may be obtained in sets of 13 with two each of the 0.2, 2, and 20 microgram standards.

2) Thorium Standards

   Sealed ampoules containing sublimed $ThCl_4$. These may be used in preparing standard thorium solutions.

   Directions for use will be furnished with the standards.

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* This work is being supported in part by a generous grant from the American Philosophical Society to the Massachusetts Institute of Technology.

3) Standard Rock Samples

The following rocks, ground to pass 40-mesh screen and be retained on 100-mesh screen are available in 100 gram samples.

Quartzite (Virginia)
Triassic diabase (Virginia)
Milford granite (Massachusetts)
Chelmsford granite (Massachusetts)
Gabbro-diorite (Massachusetts)
Columbia River Basalt (Idaho)
Berea sandstone (Ohio)
Dunite (North Carolina)
Carthage granite (Missouri)
Carthage limestone (Missouri)
Deccan Trap (India)
Kimberlite (South Africa)

These samples of rock will be analyzed for radium and thorium content and are intended for use as working standards to check methods used in extraction of radon and thoron from rock samples. They may be used for direct fusion in the electric furnace or for carbonate fusion.

All of the above samples will be analyzed at a number of laboratories equipped to make such measurements and ultimately certificates will be issued by the National Bureau of Standards. This work is in progress but will require considerable time for its completion so that final figures are available only for a part of the samples at the present time.

Accurate knowledge of the radioactive content of the materials of the earth's crust is of primary importance in many phases of geology, geophysics and cosmology. Reliable radioactive standards are also essential in studies of radium and thorium poisoning and in biological and medical investigations using the technique of radioactive indicators, or internal artificial radioactivity therapy. For the latter purposes calibrated standard sources of β-rays will be made available.

It is hoped that the standards which have been prepared by the Committee will provide all workers in these fields with a common basis for comparison of measurements and also improve the accuracy of all measurements of this type. It is likely that they will have other applications and the Committee would appreciate hearing from interested persons who may desire similar standards for their work. The Committee is also glad to cooperate as far as possible in aiding investigators to use these standards to the best advantage and welcomes specific inquiries regarding their use. It is urged that any suggestions regarding other desirable radioactive standards, not at present available, be submitted promptly to the Committee. In particular, it will facilitate the work of the Committee if those laboratories and individuals which can make use of these standards advise the Committee of their probable requirements.

Communications may be addressed to the Chairman, Professor Robley D. Evans, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

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BOOK REVIEWS

ADIRONDACK IGNEOUS ROCKS AND THEIR METAMORPHISM by A. F. BUDDINGTON. *Geological Society of America, Memoir* 7, published by the Society, December, 1939. 354 pages and colored map. 20 photographs, 30 figures.

While some knowledge of the mineralogy of the Adirondacks was known previous to 1842, Ebenezer Emmons, however, laid the foundations of the geological work upon which Kemp, Smyth, Cushing and later workers could build. Newland worked with Kemp and W. J. Miller began working in the southern Adirondacks. The author of this memoir joined the field workers under the tutelage of C. H. Smyth, Jr., while I joined Kemp. C. Nelson Dale of Hamilton College joined the western workers. Martin and Reed of Princeton and J. S. Brown of Edwards undertook additional work.

Professor Buddington has contributed largely to our understanding of the rocks of the western and northwestern portions of the area and has given a very effective summary of his work and suggestions for the solution of many of the problems of the entire area. He recognizes the difficulty of summarizing the extensive literature and evaluating the conflicting opinions of the various workers.

A brief historical review of the work done stresses the importance of Cushing's "Geology of the Northern Adirondack Region" (1905), Kemp and Ruedemann's "Geology of the Elizabethtown and Port Henry Quadrangles" (1910), and Balk's "Structural Geology of the Adirondack anorthosite" (1931).

One of Buddington's chief interests in the region is the structural relations between the rock units and hence was much impressed by J. C. Martin's publication in 1916 of "The Precambrian rocks of the Canton Quadrangle." Martin showed that the Grenville rocks, together with sills of ancient gabbro, have been compressed into large sigmoid folds. Buddington was not satisfied with W. J. Miller's suggestion that the Grenville strata had not been profoundly folded or compressed. Miller's suggestion came from the study of the southern and eastern Adirondacks; Martin's work was in the western. Consequently, was there this difference in the structure of the two regions? Subsequent work led Miller to admit that there was distinct folding in the northwestern Adirondacks but retained his original hypothesis for the rest of the region. My work would suggest that this point of view is not substantiated.

Chapter 2 deals with the Grenville series under which Buddington discusses the nature and origin of the amphibolite. Many of the bands of amphibolite have been proved in part to be thoroughly altered metagabbros, but he recognizes that some may represent original limestone country rock.

Chapter 3 is devoted to the anorthosites and gabbros. The main mass of anorthosite occupies 1200 square miles. There is a thorough discussion of the Whiteface facies named by Kemp and the Marcy anorthosite named by Miller. New chemical analyses show that the pyroxene is largely hypersthene. Buddington questions that the hornblende is primary in the hornblendic phases of the anorthosite and suggests that it is a product of change from original pyroxene. He stresses the importance of garnet contact zones studied by Kemp between the anorthosite and Grenville marble as clearly indicating the presence of an anorthosite magma. In dealing with the marginal or Whiteface facies of the anorthosite Buddington quotes the following from my papers: "This syntectic is the Whiteface anorthosite, a marginal phase of the Marcy intrusive as well as an assimilation product by magmatic replacement . . . the border facies of the anorthosite is due to syntexis and represents what I call 'xenolithic phantom gneiss'." Buddington says he is in agreement with these conclusions. His picture, therefore, is that the Grenville was first metamorphosed, partially replaced by silicates through the activity of hydrothermal solutions originating in the anorthosite magma. These ancient sediments were broken up, disintegrated and partially incorporated by the still mobile magma.

Thus Buddington departs from the theories of Bowen and Balk regarding the origin of the anorthosite and offers additional evidences for an anorthosite magma to those maintained by the older geologists.

One of the problems of Adirondack geology is whether the Whiteface anorthosite is or is not a chilled margin. Cushing, Miller, and Bowen have so interpreted it. Balk, on the other hand, argues against such a view. The question, therefore, resolves whether the border facies was not originally finer grained than that of the core. Buddington's petrographic studies show that "inherited traces of primary fabric . . . indicate that the Whiteface facies was definitely finer grained than the rock of the core . . . " He concludes that the border facies is in large part more mafic than the core, is finer grained, and is to be interpreted as a relatively chilled zone. Buddington's picture, therefore, is that the anorthosite was emplaced at moderate depths with only such deformations as are common to laccolithic or sheet-like masses. The majority of the deformations suffered by the anorthosite probably come later.

Balk's interpretation of the origin of the gabbros as concentrations of the dark silicates from the anorthosite are interpreted by Buddington as included layers of metamorphic limestone. I have been unable to accept Balk's theory of the origin of the gabbros in the eastern Adirondacks; apparently Buddington has the same difficulty.

The ages of the gabbros, either within or without the main anorthosite mass, are discussed with the conclusion that many are older than the syenite and granite but younger than the anorthosite. I suspect that this is as near to the truth as is possible to state at the present time. It is possible that there are other gabbros which have other ages, but until more detailed work is done Buddington's opinion will probably stand.

Chapter 4 is devoted to the Diana quartz syenite complex. Buddington has been a pioneer in Adirondack work in applying our knowledge of stratiform, gravity-differentiated sheets of siliceous composition to the Diana complex. He has recognized seven facies consisting of pyroxene syenite, pyroxene quartz syenite, feldspar-rich pyroxene syenite, transitional quartz syenite, mafic hornblende-pyroxene quartz syenite, hornblende quartz syenite, and hornblende granite. He employs two methods in estimating the composition of the primary magma, first by averaging all the Rosiwal analyses, and second by making a weighted average based upon the approximate distribution of the different types of facies mapped in the field. Both methods give similar results leading to the conclusion that the transitional pyroxene quartz syenite represents the primary composition. The result of this careful work leads to the conclusion that the intrusives came in as great sheet-like masses, experienced differentiation after emplacement, and experienced metamorphic changes due to stress afterwards.

In Chapter 5 Buddington summarizes similar studies of other quartz syenite complexes within the region and reaches similar conclusions.

Chapter 7 discusses the batholithic masses of granite which constitute the bulk of the intrusives in the western Adirondacks. He believes that these are younger in age than the

Diana, Santa Clara, and Tupper-Saranac complexes. They are hornblendic granites with local syenite differential facies. Biotite enters some of these rocks in relatively small masses, usually in association with members of the Grenville series. These younger granites show transgressive character. In one case the granite cuts across the northern flank of the Santa Clara anticlinorium. Some of these later granites are probably phacoliths which are well shown in the Gouverneur and Canton quadrangles.

Chapter 9 is an excellent summary of the Adirondack igneous complex as a whole. There is a brief discussion of the term "Laurentian granite," a term which was in current use some years ago as the result of Cushing's papers. Buddington is not sure he can recognize the presence of an older granite antedating the introduction of the complexes and the younger granites.

Chapter 10 deals with regional metamorphism, their zones and facies. He recognizes four different zones: (1) where cataclasis is predominant, (2) where crushing and recrystallization prevail, (3) Crushing and recrystallization have occurred with the development of granoblastic gneisses, and (4) where crushing is subordinate. Under (4) he says the rocks exhibit textures due primarily to the crystallization of the magma and show magmatic flowage.

Smyth postulated three stages in the formation of different facies: (1) the formation of secondary hornblende from primary pyroxene, (2) cataclastic crushing, and (3) recrystallization. Buddington's studies have led him to conclude that Smyth was correct, that these changes took place after crystallization, not during the late magmatic stage. The Diana complex shows all types of metamorphism from massive rock through augengneisses to ultracataclastic mylonite.

He discusses the garnet reaction rims which he calls chronolite and reaches the conclusion that they were formed after the complete solidification of the rocks as the result of regional metamorphism subsequent to the emplacement of the quartz syenite.

Chapter 11 discusses the origin of the metamorphism. Most of the Adirondack rocks show evidences of pronounced crushing and deformation. This foliation was interpreted by the early writers, including Kemp, Cushing, Ogilvie, Smyth, and Newland, as due to metamorphism after the rocks were solid. Balk, however, maintained that it was due to differential flowage and movement during the magmatic stage. Buddington has devoted arduous labors to this problem, and reaches the conclusion that the foliation in microstructures now seen were developed largely by deformation in the solid state with the possible exception of part of that in the younger granites.

The pattern of the regional foliation is shown along the northwest border where folds in the Grenville are overturned toward the southeast, and in the southern portion of the mountains the folds are overturned toward the north.

Buddington estimates the depth of burial of anorthosite to account for the deformation and metamorphism by suggesting that there may have been three or four miles of rock between the anorthosite massif and the base of the Diana complex. It seems probable that the major deformation occurred during the cycle of emplacement of the younger granites.

Professor Buddington is an eminent structural and metamorphic petrologist and has interpreted the Adirondack rocks chiefly along these lines. Balk, on the other hand, stresses the field methods of Cloos. I should think that the differences in interpretation between these two are what would be expected. Buddington's memoir, which is really a monograph, is a splendid contribution and summary of the major problems of the region. He has solved many problems. He likewise opens new problems for future workers in this interesting region.

The volume maintains the unusually high standards in typography, illustrations, and binding we all expect from the Geological Society of America. I congratulate the author and the Society on an outstanding piece of work.

HAROLD L. ALLING

DIE ENSTEHUNG DER GESTEINE. Ein Lehrbuch der Petrogenese. Tom. F. W. Barth, Carl W. Correns, and Pentti Eskola. Julius Springer, Berlin, **1939,** 422 pp., 210 text figures. Price R.M. 30, less 25%.

In contrast with many German books, the book under review is a very concise treatment of the subject of petrogenesis. Some parts are so concise that they may be difficult reading for a student who has not already a considerable knowledge of the subject. If used as a text, the instructor would do well to elaborate many of the sections. The book adheres closely to the subject given in the title, and little space is given to description and classification.

The three authors are among the leading students in their respective fields. The topics treated are well selected and cover the latest developments in the science. The authors have a better knowledge of American literature and a better understanding of the American point of view than do most European authors.

The part on the eruptive rocks by Barth includes a discussion of the crystallization of silicate melts illustrated by many equilibrium diagrams. The section on the magma discusses the viscosity, temperature, gas content, and other characteristics of the magma. A longer section discusses magmatic differentiation and the origin of rocks. Barth recognizes the growing conviction that some granitic rocks have been formed by the melting of sediments or other rocks.

The section on the sedimentary rocks by Correns is a quantitative discussion of the subject and includes many diagrams. It includes sections on weathering, the clastic sediments, chemical and biogene sediments and diageneses. Grain-size and shape, mineral composition, and similar topics are discussed.

The section on the metamorphic rocks by Eskola includes sections on texture, including Sander's method of study, recrystallization, mineral facies, metasomatism, and normal metamorphism. In the section on mineral facies Eskola has wisely placed less emphasis on igneous facies than in his former works. Most American students of the glaucophane schists will not admit that they are formed at great depth.

Esper S. Larsen

THE PETROLOGY OF THE SKAERGAARD INTRUSION, KANGERDLUGSSUAQ, EAST GREENLAND. L. R. Wager and W. A. Deer. Meddel. om Grønland, Bd. 105, No. 4, **1939.** 335 pp., 68 figures, 27 plates, one map. Price, Kr. 20.00.

This is a book of very great importance both to descriptive petrology and to petrogenesis. It describes an intrusive body that occupies an area of 50 square kilometers and has the form of an inverted funnel. The intrusive is divided into a layered series that occupies the central part of the complex and a border series that forms a narrow envelope next to the sides and at the top. The contacts between the two are fairly sharp in some parts and indefinite in others.

The layered series is made up of alternate, nearly horizontal bands of darker and lighter material arranged like inverted saucers. Several types of banding are described.

The border series is also layered but the layers are parallel to the contacts. The rocks of both series are gabbros. In the lower part of the layered series the feldspar is labradorite and the mafic minerals have a moderate iron content; the soda content of the feldspar and the iron content of the femic minerals increase upward and in the upper horizon the feldspar is oligoclase-andesine and the olivine is fayalite. The border series varies in a similar way from the contact inward.

The layering and magmatic differentiation are believed to be due to crystallization on the walls of the liquid phase of material brought into place by convection currents. The authors believe that this body shows that with strong fractionation a basaltic magma differentiates to a basaltic magma enriched in iron.

The small amount of siliceous rocks present are believed to have formed from assimilation.

Esper S. Larsen

PROCEEDINGS OF THE SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences, Philadelphia, Pa.

A stated meeting of the Philadelphia Mineralogical Society was called to order by President W. Hersey Thomas on December 7, with 48 members and 30 visitors in attendance.

Dr. A. Williams Postel addressed the Society on the results of his studies on the granodiorites of the Philadelphia area. He first described the various facies of the Wissahickon schist, originally a sedimentary series of impure shales, now so highly metamorphosed as to be in the kyanite and sillimanite grades of metamorphism. The schist has been intruded by a series of igneous rocks, the earliest of which were basic and formed sills which have been metamorphosed to hornblende gneiss. Later, there was an intrusion of massive gabbro, and this was followed by the granodiorites—first the Springfield quarry type, then aplite veins, and finally the Ridley Park quarry type.

The Springfield granodiorite is porphyritic, coarse grained and has a gneissic structure parallel to that of the surrounding schists, but the microcline phenocrysts show no cataclastic structures. The basic sills in the Wissahickon vary in thickness and where they are in contact with the granodiorite, the intensity of their alteration is related to their thickness. Only the largest of the sills show unaltered interiors, the rest have been completely changed to biotite gneiss. The Springfield granodiorite is always associated with crushed Wissahickon gneiss, in which the stress mineral kyanite is present, denoting a sheared zone. Near contacts with the gabbro the granodiorite contains inclusions of gabbro and impregnates the gabbroic wall rock with quartz and alters its pyroxene to hornblende and biotite.

The speaker suggested three possible modes of emplacement for the Springfield granodiorite—first, that it was a normal silicate magmatic intrusive and that its foliation was imposed at the same time that the schist received its foliation and metamorphism. However, this could not be the case as the Springfield granodiorite also injects the gabbro which has no foliation or metamorphic structure, thus the granodiorite must be later than the metamorphism of the schist. A second possibility is that the magmatic granodiorite might have intruded the already metamorphosed Wissahickon schist, injecting it lit-par-lit, and assuming its structure. But a difficulty arises from the fact that the foliation of the inclusions in it are without exception parallel to the foliation of the country rock. This leaves only one interpretation. Dr. Postel believes that potash-silica-rich hydrothermal emanations from below have soaked and reacted with the Wissahickon schist to produce the Springfield granodiorite, and that it was never a true intrusive of magmatic form. In support of this hypothesis, he shows that the microcline porphyroblasts of the granodiorite have as inclusions plagioclase and quartz from the earlier schist, that seeming inclusions of basic rocks in the granodiorite are really altered basic sills, that the great variation in composition of the granodiorite is to be expected in a rock which formed as a result of reaction with the Wissahickon schist, which did not have a constant composition to begin with, and finally the constant association of the granodiorite with shear zones in the schist, which could form avenues of approach for the reacting emanations.

The Ridley Park granodiorite has a more constant composition and always occurs in dike form, the width of which is seldom more than ten feet. It is the speaker's opinion that the Ridley Park granodiorite shows the composition of the underlying mass from which the Springfield type emanations and the aplites have originated. The age of these intrusive rocks cannot be determined until the age of the Wissahickon schist is established. However, if they are the hydrothermal phases of the Port Deposit, Md., magmatic rocks, then they are post-Ordivician, as proven by Cloos and Hershey, who showed that inclusions in the igneous rocks had post-Ordivician structures of which the igneous rocks were free. Dr. Postel showed a structural and petrographic map of all the known outcrops found in the area covered by the rocks he studied, and illustrated his points with pictures of outcrops, photomicrographs, and results of chemical analyses.

Louis Moyd, *Secretary*

NEW YORK MINERALOGICAL CLUB, INC.

The American Museum of Natural History, New York City, Dec. 20, 1939

The meeting was called to order by President Lee with 39 members and guests present. After the brief business meeting Mr. Lee presented the speakers of the evening, O. Ivan Lee, and F. H. Pough, who addressed the Club upon "The Spruce Pine Pegmatites." Mr. Lee gave directions for reaching the district and described some of the individual quarries and their products. Dr. Pough described some of the quarries he visited in the fall and showed some lantern slides made by binding the garnet inclusions of the mica between two plates of glass and projecting the specimen as a lantern slide. This method proved very successful and the color zones were clearly visible in the flattened garnets. Both talks were well illustrated with color slides.

F. H. Pough, *Secretary*

MINERALOGICAL SOCIETY: LONDON

General meeting held in the apartments of the Geological Society of London on January 25th, 1940. Mr. Arthur Russell, M.B.E., President, in the Chair.

The following papers were read:—

(1). *The structure of orthoclase.* By Dr. S. H. Chao, Mr. A. Hargreaves, and Dr. W. H. Taylor.

Quantitative *x*-ray methods have been applied to the determination of the crystal structure of a typical orthoclase containing nearly pure potash-feldspar. The experimental procedure and the accuracy of the work are discussed, and the details of the structure are described.

(2). *The existence of reversible photosensitivity in some artificial materials containing rutile.* By Dr. W. O. Williamson (Communicated by the General Secretary).

Reversible darkening in daylight is shown by three types of material made from artificial anatase:

(a) Anatase partly recrystallized by heat treatment, under "dry" conditions in the presence of iron or manganese, with the production of rutile. Certain iron-containing samples show a strikingly rapid darkening in daylight. This darkening is more pronounced in violet than in red light and is reversed on heating to below 100°C.

(b) Anatase completely recrystallized in the presence of molten sodium chloride. The resulting product contains rutile and a sodium titanite in varying proportions.

(c) Anatase converted into rutile by heating in the presence of iron, in an atmosphere containing hydrogen chloride.

The photosensitivity is held to depend on the entry of impurities into rutile crystals. Tentative explanations of it are given and the possibility of a connection with the known photosensitizing activity of titanium dioxide is stressed.

(3). *Notes on the occurrence of fluorite in the West Cumberland iron mines and in the Lake District of Cumberland and Westmorland.* By Mr. Arthur Russell.

The presence of fluorite in the haematite ore bodies of West Cumberland, apart from its purely mineralogical interest, is of some importance as affording a possible clue to the much-debated question of the source of mineralization. A detailed description is given of its occurrence at a number of mines, drawings of crystals are given, and the sequence of the associated minerals is recorded.

Fluorite, hitherto regarded as a rare mineral in the Lake District, is described from three localities, two of which are new.

(4). *A new method for the preparation of thin sections of clays.* By Mr. A. V. Weatherhead (Communicated by the General Secretary).

By the application of pyroxylin to suitably prepared clay samples, cellulose "peels" are obtained, which, when mounted in Canada balsam, enable a thorough examination to be made in polarized light under the microscope. Oil immersion objectives can be employed and under high magnifications the author has observed certain interesting authigenic constituents present in some clays. So far as can be ascertained these constituents have not yet been recorded and may form the basis for future research on these very fine-grained plastic rocks.

(5). *A note on crystallographic calculations.* By Dr. Max H. Hey.

Solutions are given for the calculations of the elements of a monoclinic crystal from three fundamental angles in four cases where an unusual selection of fundamentals makes the usual methods of calculation impossible. One of these cases may be of practical interest for poorly developed crystals.

NEW MINERAL NAMES

Falkmanite

PAUL RAMDOHR AND OLOF ÖDMAN: Falkmanit, ein neues Bleispiessglanzerz, und sein Vorkommen, besonders in Boliden und Grube Bäyerland. *N. Jahrb. Min., Beil-Bd.* **75,** Abt. A (1939), 315–350, 2 figs., 4 pls.

NAME: In honor of Oscar Falkman, General director of the Bolidens Gruvaktiebolag.

CHEMICAL PROPERTIES: A sulfantimonide of lead, probably $Pb_3Sb_2S_6$. Analysis (by Th. Berggren) [on sample contaminated with bournonite (10%), arsenopyrite (1.5%), jamesonite, covellite, etc., (3%)] Pb 52.97, Sb 22.48, Bi 1.16, Cu 1.52, S 19.32, Se 0.42, As 1.00, Fe 0.50, Ag 0.002, Au 0.001, Insol 0.56; total 99.93.

CRYSTALLOGRAPHICAL PROPERTIES: Monoclinic. Habit tabular to (102) or acicular along *b*-axis, or with lenticular cross section due to strong development of (101) and (102). Forms (001), (106), (102), (101), (302), (100).

PHYSICAL PROPERTIES: Color, metallic gray-black toward lead gray. Streak black, when rubbed down light reddish to light brown. Cleavage (010), sometimes distinct, breaks to fine needle or fiber-like masses, along the *b*-axis. Hd. 2½. G. 6.24.

METALLOGRAPHICAL PROPERTIES: Very similar to jamesonite and boulangerite. Cleavage distinct in sections nearly parallel to the *b*-axis, polish very good, color galena white, anisotropism distinct. Deep red inner reflection. Etch: positive with HNO_3, effervescences with slow blackening. Negative with HCl, KCN, $FeCl_3$, $HgCl_2$, KOH. Twinning rare.

OCCURRENCE: Found as fibrous aggregates at Bäyerland Mine, Bäyerland, near Waldsassen, Upper Palatinate, Germany; with galena, jamesonite, bournonite, geocronite, arsenopyrite, chalcopyrite, blende, pyrrhotite, pyrite, tetrahedrite, valleriite in a quartz gangue. Also at Boliden, Sweden, with numerous other minerals, chiefly bournonite, galena, danaite, pyrite, chalcopyrite, tetrahedrite, bismuth, gudmundite and jamesonite; Minas Geraes, Brazil, with pyrite in quartz; Sala, Sweden, with galena and pyrite.

DISCUSSION: Differs from boulangerite (given as $Pb_{2.5}Sb_2S_{5.5}$) in composition, crystallography and density. Slight but appreciable differences are shown by the *x*-ray powder diagrams and by their metallographical properties.

W. F. FOSHAG

Falkmanite

J. E. HILLER: Über den Falkmanit: *Zeits. Krist.*, **102** heft 2, 138–142 (1939).

CRYSTALLOGRAPHICAL PROPERTIES: Monoclinic. Acicular tabular, parallel to *b*. $a=24.93$ Å; $b=8.10$ Å; $c=14.51$ Å. $\beta=79°10'$. $a:b:c=3.077:1:1.791$.

W. F. F.

Calcio-gadolinite

TOSHIO NAKAI: On calcio-gadolinite, a new variety of gadolinite found in Tadati Village, Nagano Prefecture. *Bull. Chem. Soc. Japan*, **13,** No. 9, 591–594 (1938).

CHEMICAL PROPERTIES: A gadolinite rich in calcium, $Be_2(Fe'', Fe''')(\Sigma Ce, Ca)_2Si_2(O, OH)_{10}$. Analysis CaO 11.91; MgO 0.14; MnO 0.84; FeO 11.24; BeO 10.73; Al_2O_3 1.68; Fe_2O_3 7.65; Ce_2O_3 4.69; La, Y_2O_3 24.47 [mean atomic weight about 130]; ThO_2 0.80; SiO_2 23.89; U_3O_8 0.10; H_2O- 0.14; H_2O+ 2.05; sum 100.34%.

PHYSICAL PROPERTIES: Color black, streak greenish gray. G. = 4.5. Weakly radioactive. Pleochroism strong, Z (dark brown) > Y (light yellow) = X (light brown). $\alpha=1.765$, $\beta=1.774$, $\gamma=1.787$.

OCCURRENCE: Found massive or in rough prisms in a pegmatite, associated with allanite, zircon, fergusonite, etc., at Tadati Village, 12 km. N.N.E. of Naegi, Japan.

W. F. F.

α, β, γ, δ, ϵ, montmorillonite
α, β, γ, δ, ϵ, sepiolite
Alumodeveillite
Hydromagniolite
Hydrosyalite

N. E. EFREMOV: On the classification of some magnesium silicates and their alumoanalogues. *Compt. Rend. (Doklady) Akad. Sci., U.R.S.S.*, **24**, 287–289 (1939).

Various ratios of $Al_2O_3:SiO_2:H_2O$ and of $MgO:SiO_2:H_2O$ are given α, β, γ, δ, ϵ designations. The undefined terms alumodeveillite, hydromagniolite and hydrosyalite also appear to be new.

W. F. F.

Simpsonite

[Meta-simpsonite]

H. BOWLEY: Simpsonite (sp. nov.) from Tabba Tabba, Western Australia. *Jour. Roy. Soc. W. Australia.* **25**, 89–92 (1938–39).

L. E. R. TAYLOR: *X*-ray studies of simpsonite. *Ibid.*, 93–97, 3 figs.

NAME: In honor of Dr. E. S. Simpson, Government Mineralogist of Western Australia.

CHEMICAL PROPERTIES: Believed to be a tantalate of lime and alumina, $2H_2O \cdot CaO \cdot 5Al_2O_3 \cdot 4Ta_2O_5$. Analysis (on partially altered crystals) (D. G. Murray): Ta_2O_5 72.31, Nb_2O_5 0.33, SnO_2 2.00, FeO 0.16, MnO 0.08, CaO 3.40, Fe_2O_3 0.14, Al_2O_3 16.75, K_2O 0.24, Na_2O 1.16, PbO 0.42, F 0.21, H_2O+ 1.35, H_2O- 0.20, SiO_2 1.78. Sum 100.53. Another analysis (J. N. A. Grace) and three partial analyses are also given. Unattacked by HCl or H_2SO_4 but readily decomposed by fusion with caustic alkalies, alkaline carbonates and potassium bisulfate.

CRYSTALLOGRAPHICAL PROPERTIES: Hexagonal. Habit tabular or short prismatic. *X*-ray examination indicates hexagonal symmetry with $c = 4.5$Å, $a = 6.2$Å.

PHYSICAL AND OPTICAL PROPERTIES: Colorless. G. (mixed with its alteration product) 5.92–6.05. Uniaxial, positive. $n = 2.06$.

OCCURRENCE: Found as incomplete and partially altered crystals in quartz biotite pegmatite, near the tantalite workings at Tabba Tabba, Western Australia.

Phosphorrösslerite
Arsenrösslerite

O. M. FRIEDRICH AND J. ROBITSCH: Phosphorrösslerite ($MgHPO_4 \cdot 7H_2O$) als Mineral aus dem Stüblbau zu Schellgaden. *Zentralb. Mineral. Geol. Paleon.*, Abt. A, Nr. 5, 142–155 **(1939)**, 11 figs.

NAME: From its isomorphous relationship to rösslerite.

CHEMICAL PROPERTIES: Hydrous acid phosphate of magnesium, $MgHPO_4 \cdot 7H_2O$. Analysis (J. Robitsch): MgO 16.28, P_2O_5 28.07, H_2O (acid) 3.65, H_2O (crystallization) 50.86, Insol. 0.08; Sum 98.94.

Easily soluble in dilute HCl or HNO_3. Readily attacked by water. In closed tube readily yields much water and turns white. Upon long exposure to air gradually turns white. B. B. on platinum wire, gives no flame and leaves a mass very difficultly soluble in dilute HCl.

CRYSTALLOGRAPHICAL PROPERTIES: Monoclinic, prismatic. $a:b:c=0.4455:1:02602$. $\beta=94°56'$. Forms: b (010), a (100), p (110), r (011), q (120), w (111), l (140), o ($\bar{1}11$). Habit equidimensional or short prismatic, rarely tabular; often in twin-like intergrowths. Also skeletal crystals, drusy crusts and kidney or hyalite-like forms.

PHYSICAL AND OPTICAL PROPERTIES: Colorless to yellow or honey brown. $G=1.725$. $Hd=2\frac{1}{2}$. Cleavage none. Fracture conchoidal.

Biaxial, negative. $2V=38°70'$. $\alpha=1.477$, $\beta=1.485$, $\gamma=1.486$. Plane of the optic axes almost parallel to a (100) and normal to b (010). $X=a$, $Y=b$, $Z\wedge c=6.5°$.

OCCURRENCE: Found as a secondary formation as crusts on, and as individual crystals, in accumulated muds in old mine stopes in the Stüblbau works at Schellgaden, Germany.

The arsenic analogue, rösslerite, is referred to as arsenrösslerite.

W. F. F.

Communication

The remark in A. L. Howland's paper on "Specularite-alunite mineralization at Hickeys Pond, Newfoundland" (this Journal, vol. **25**, p. 42, 1940) that "elsewhere [other than at Goldfield, Nevada], however, alunite is not associated with sulphide minerals, other than pyrite" reminds me that cinnabar is associated with alunite in the rhyolites east of Beatty in western Nevada, where the rhyolites have been silicified and alunitized in belts hundreds of yards long and as much as 200 feet wide.[1]

ADOLPH KNOPF

[1] Knopf, Adolph, Some cinnabar deposits in western Nevada: *U. S. Geol. Survey, Bull.* **620,** 64–68 (1915).

Errata

The following corrections should be made in article by T. T. Quirke and W. C. Lacy, vol. **24,** 705–724 (1939).

Page 713, error in calculation, for i of 80° calculated value should be 42°47′, instead of 42°43′; in consequence the figure in the next column should be −2°47′ in place of −2°43′.

The same recurs in the Table of Computations page 718, for 80° r_{e1} should be 33°29′, in place of 33°36′. r_n-r_{e1} should read 5°59′, in place of 5°52′, and I should be 9°18′ in place of 9°07′, and $r_{e1}+I$ should read 42°47′, in place of 42°43′.

On page 722 a typographical error makes difference between observation and theory for i 70° read −0°07′ instead of −1°07′.

In Table 2 on page 96 (February issue), substitute "NaF" for "Acid NaF" in the first column preceding Li F.